PB82-110271

# Airborne Radioactive Emission Control Technology
## Volume II

Dames and Moore
White Plains, NY

Prepared for

Office of Radiation Programs
Washington, DC

Mar 80

U.S. Department of Commerce
National Technical Information Service
NTIS

**BIBLIOGRAPHIC DATA SHEET**

**1. Report No.**
ORP Contract Report 81-5B

**2.**

**3. Recipient's Accession No.**
PB82 110271

**4. Title and Subtitle**
Airborne Radioactive Emission Control Technology
Vol. 2

**5. Report Date**
March 1980

**6.**
U272025

**7. Author(s)**
Skoski, L., Berlin, R., Oztunali, O., Re, G., et al

**8. Performing Organization Rept. No.**

**9. Performing Organization Name and Address**
Dames & Moore
20 Haarlem Avenue
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**10. Project/Task/Work Unit No.**

**11. Contract/Grant No.**
68-01-4992

**12. Sponsoring Organization Name and Address**
Office of Radiation Programs
U.S. Environmental Protection Agency
401 M. St. SW
Washington, D.C. 20460

**13. Type of Report & Period Covered**

**14.**

**15. Supplementary Notes**

**16. Abstracts**

This report reviews the current and future control technology for airborne emissions from a wide variety of industries/facilities, including uranium mining and milling, other nuclear fuel cycle facilities, other NRC-licensed and DOE facilities, fossil fuel facilities, selected metal and non-metal extraction industries, and others. Where specific radioactivity control technology is lacking, a description of any existing control technology is given. Future control technology is assessed in terms of improvements to equipment performance and process alterations. A catalogue of investigated research on advanced control technologies is presented.

**17. Key Words and Document Analysis. 17a. Descriptors**

Airborne radioactivity source terms
control technology effectiveness
control technology costs
effluent system designs
research and development

**17b. Identifiers/Open-Ended Terms**

**17c. COSATI Field/Group**

**18. Availability Statement**
Release Unlimited

**19. Security Class (This Report)**
UNCLASSIFIED

**20. Security Class (This Page)**
UNCLASSIFIED

**21. No. of Pages**

**22. Price**

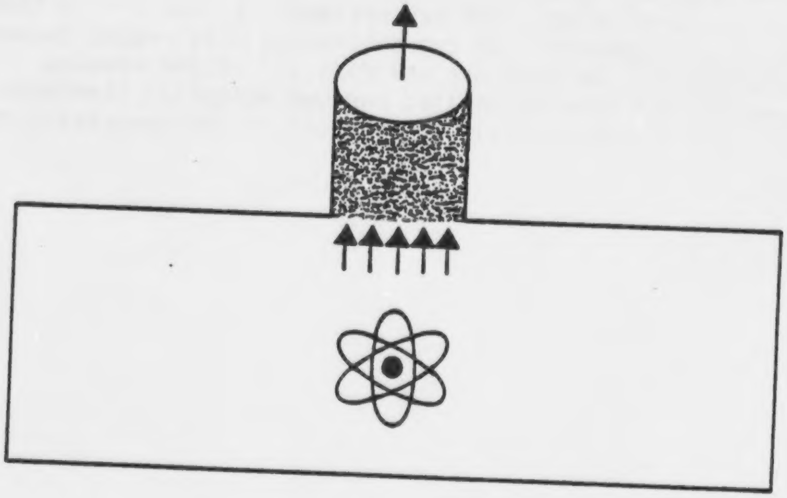
ORP Contract
Report 81-5B

PB82-110271

# AIRBORNE RADIOACTIVE EMISSION CONTROL TECHNOLOGY

## VOLUME II

DAMES & MOORE
WHITE PLAINS N.Y.



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OFFICE OF RADIATION PROGRAMS
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

## NOTICE

This report was prepared by Dames & Moore for the United States Environmental Protection Agency's Office of Radiation Programs (ORP) under Contract No. 68-01-4992. ORP has reviewed it, and the contractor has responded to our comments. We are publishing this report because of its useful information. We have not verified all of the results ourselves, however; nor have we applied our own editorial standards to the text. ORP does not necessarily publish all of the contractor reports it receives.

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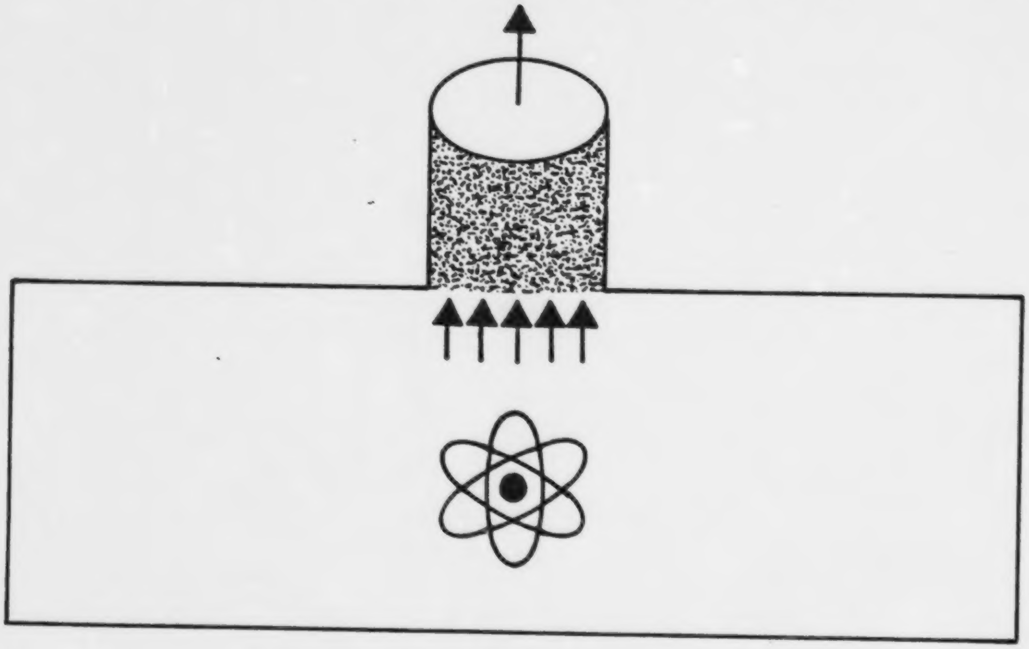

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# CHAPTER II

## Section 6: Selected Metal and Non-Metal Extraction Industries

### Background

Certain metal and non-metal extraction industries are potential sources of technologically enhanced natural radioactivity (TENR). Technologically enhanced natural radioactivity is the suggested term used to describe any increase in the amount of natural radiation above background to which the public may be exposed to as a result of some activity undertaken by man.(6-1) Included under this term is the increased level of radioactivity due to the mining and milling of radioactive ores, e.g., uranium (Chapter II, Section 2).

Exposure to TENR may also result from the mining and/or milling of certain commodities which are primarily produced for their non-radioactive elemental contents, but which may have elevated levels of natural radioactivity. These industries include stone, iron, phosphate, bauxite and fluorspar.

This section will review the possible contributions of these industries to airborne TENR and the control technologies employed therein.

### Industry Selection

The two basic criteria employed in the selection of the extraction industries to be studied were the amount of material processed and the known or implied association of elevated (above background) levels of natural radionuclides in the material being processed. These two criteria will be discussed separately.

### Industry Size

The total amount of material processed by an extraction industry includes the amount of ore mined and the amount of waste material (topsoil, waste rock, and overburden) produced. Table 6-1 presents domestic extraction industries that processed more than 10 million short tons of material, listed in order of total material processed. The data are for 1975, the most recent year for which data are readily available.(6-2)

Based on this criteria the crushed stone, copper, iron, and phosphate rock industries were chosen for investigation. The sand and gravel industry was deleted since processing operations, if any, usually involve merely washing and screening. Thus sand and gravel should not be a significant source of airborne TENR.

### Radionuclide Associations

The second criteria used was the known or implied association of elevated levels of radionuclides with the extracted material. The known radionuclide association with phosphate, copper, and bauxite, and the implied radionuclide association with fluorspar and iron fall under this criteria.

### Data Acquisition

The gathering of topical information on approximately 95 commodities of economic importance is currently part of the function of the Bureau of Mines. A specialist in one or more commodities is employed to direct the collection, processing and dissemination of data dealing with the respective commodity.

With the exception of crushed stone and clay, the selected industries are not widely distributed but are confined to certain

## TABLE 6-1

### Material Handled in U.S. Extraction Industries - 1975[a]
(Thousands of Short Tons)

| | | Total | Crude Ore | Waste | Marketable Product | Ratio[b] |
|---|---|---|---|---|---|---|
| 1. | Stone - Crushed & Broken | 971,000 | 899,000 | 71,500 | 900,000 | 1.1:1 |
| 2. | Copper | 959,000 | 269,000 | 690,000 | 1,390 | 689.9:1 |
| 3. | Sand & Gravel | 789,000 | 789,000 | --- | 789,000 | 1.0:1 |
| 4. | Coal[c] | 655,000 | --- | --- | --- | --- |
| 5. | Iron | 497,000 | 239,000 | 258,000 | 84,400 | 5.9:1 |
| 6. | Phosphate Rock | 402,000 | 186,000 | 216,000 | 48,500 | 8.3.1 |
| 7. | Uranium | 164,000 | 6,940 | 157,100 | 11 | 14909:1 |
| 8. | Clays | 80,500 | 43,400 | 37,100 | 43,400 | 1.8:1 |
| 9. | Titanium, ilmenite | 36,400 | 32,800 | 3,600 | 702 | 51.9:1 |
| 10. | Gypsum | 23,800 | 10,100 | 13,600 | 9,750 | 2.4:1 |
| 11. | Gold[d] | 19,390 | 10,120 | 9,240 | 0.0225 | 861,778:1 |
| 12. | Potassium Salts | 18,300 | 17,800 | 460 | 2,080 | 8.8:1 |
| 13. | Bauxite[e] | 16,600 | 3,290 | 13,300 | 1,890 | 8.8:1 |
| 14. | Salt | 15,600 | 14,900 | 704 | 14,000 | 1.1:1 |
| 15. | Lead | 12,300 | 9,850 | 2,450 | 568 | 21.6.1 |
| 16. | Sodium Carbonate (nat.) | 12,100 | 8,010 | 4,050 | 4,040 | 3.0:1 |
| 17. | Zinc | 11,400 | 8,580 | 2,780 | 333 | 34.2:1 |
| 18. | Other Metals[f] | 72,100 | 29,444 | 42,652 | --- | --- |
| 19. | Other non-metals[g] | 56,463 | 22,207 | 34,320 | --- | --- |

---

[a] Taken from reference 6-2.

[b] Ratio of total material handled to the amount of marketable product.

[c] Bituminous, lignite, and anthracite.

[d] Lode and placer.

[e] Surface mined.

[f] Mercury, silver, tungsten, antimony, beryllium, manganiferous ore, molybdenum, monazite, nickel, platinum-group metals, rare-earth metals, tin, vanadium, and bauxite (from underground mines).

[g] Abrasives (stone, emergy, garnet, and tripoli), asbestos, barite, diatomite, feldspar, fluorspar, mica (scrap), perlite, pumice, dimension stone, talc, soapstone, pyrophyllite, aplite, boron minerals, graphite, greensand marl, iron oxide pigments (crude), kyanite, lithium minerals, magnesite, millstones, olivine and vermiculite.

mineralized areas. Bureau of Mines Liaison Officers were contacted in each of the major production centers for guidance in obtaining data on radionuclide airborne release and controls used to limit this release. Where data was lacking, information on the emission and control of particulate matter was obtained.

In general, much of the information used in this study was provided by state and federal agencies. Unlike the uranium study (Chapter II, Section 2), reliance on previously published studies was necessary due to the magnitude of the effort required to survey representative plants in each industry. This would have been necessary to obtain specific data on all the major airborne release points (including area sources) and their associated controls. For example, some industries control airborne emissions from 30 to 60 separate release points in an ore processing scheme.

The information obtained in this manner was supplemented by library and computer searches and by direct contact with cognizant individuals.

In the following sections, information obtained for each industry will be presented using generally the following format:

1. Industry Description
2. Ore Geology and Radionuclide Content
3. Process Description
4. Airborne Radionuclide or Particulate Emissions
5. Airborne Radionuclide or Particulate Emission Controls

Although variations may occur among the industries, the above format was generally consistent from industry to industry. The rationale or content of each subheading is briefly discussed.

## Industry Description

A description of each industry is necessary to review its magnitude or complexity. The description generally includes the amount of the material processed, the number of companies and/or plants involved, and the source and distribution of the material processed.

## Ore Geology and Radionuclide Content

A general geologic description of the extracted material along with any available data on the radionuclides in the ore is presented in this section.

In those industries for which radionuclide data were not available some qualitative correlations could be made by assuming that the radionuclide content of the extracted material is similar to the host rock.

A brief review of radionuclide contents of various rocks is presented in the review of the Stone Industry.

## Process Description

The operations involved in obtaining raw material and its subsequent processing are described in detail under this subheading. Material associated with the ore (i.e., overburden, waste rock, gangue) is discussed in reference to handling, processing and ultimate disposition where possible. Ore processing operations were considered to the point of primary product production e.g., pig iron, alumina, or blister copper.

## Airborne Radionuclide or Particulate Emissions

Little data exists on the radionuclide emissions for the reviewed extraction industries. Consequently, this subsection also reviews data on airborne particulates and fugitive dust.

## Airborne Radionuclide or Particulate Emission Controls

As with release data, no controls were identified to specifically limit radionuclide emissions. Consequently, particulate controls were reviewed as secondary controls.

The available information presented on the controls includes control type, effectiveness, capital and operating expenses, and residuals generated. The information ranges from extensive to meager depending upon the process and industry.

## Crushed Stone Industry

### Industry Description

The stone industry is the largest extraction industry in the United States in terms of the quantity of material processed. Total output of stone for 1977 was 955.4 million tons* valued at $2.46 billion.(6-3) Sand and gravel production was second with 898 million tons valued at $1.86 billion (f.o.b.), followed by coal (bituminous and lignite) with a 1977 production of 685 million tons valued at $14.4 billion (f.o.b. mines) (6-4).

Currently, the Bureau of Mines maintains nine separate categories of stone.(6-5) These are presented in Table 6-2. It should be noted that the Bureau generally relies on individual producers to classify the product.

Stone is also classified by the Bureau by the type of usage, being either crushed or dimension. Dimension stone is cut shaped stone used primarily for building stone (62%) and monuments (20%). The entire output of dimension stone in 1977 was 1.4 million tons, or less than 0.2% of the output of crushed stone.(6-5) Due to the negligible contribution of dimension stone to the stone industry, only crushed stone will be further considered.

Crushed stone was produced in all but two states for a total 1977 output of 954 million tons. During this time, there were 1,894 companies operating 5,177 quarries.(6-3) Individual plant capacities ranged from less than 25,000 tons per year to more than 15 million tons per year, with 40 percent of the plants in the former category, accounting for only 2 percent of the total output. Plants producing

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* Tons refers to short tons (2000 lbs), unless stated otherwise.

## TABLE 6-2

### Classes of Stone*

| Type | Name | Description |
|---|---|---|
| Igneous | Granite | A coarse-grained igneous rock containing megascopic quartz, averaging 25%, much feldspar, and mica or other colored minerals. Commercially, the term is loosely used for any light-colored, coarse-grained igneous rock, including quartz-diorites, syenites, quartz-porphyrites, gabbros, and metamorphic schists and gneisses. |
| Igneous | Traprock | All dense, dark, fine-grained igneous rock. |
| Metamorphic | Marble | Commercially any calcareous rock that is sufficiently hard and coherent to take a good polish. |
| Metamorphic | Slate | A fine-grained metamorphic rock which breaks into thin slabs or sheets. Composed of micas, chlorite, quartz, hematite, clays and other minerals. |
| Sedimentary | Limestone | A sedimentary rock containing calcium carbonate (calcite), or calcium magnesium carbonate (dolomite) or any combination of these two carbonates at least to the extent of 50% of the rock. It may be pure calcite or dolomite, or it may be bituminous (impregnated with bituminous matter) or silicious (containing silica). |
| Sedimentary | Marl | A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells. It may range from low to high in shale or clay content. |
| Sedimentary | Sandstone | A cemented or otherwise compacted detrital sediment composed predominantly of quartz grains, the grades of the latter being those of sand. Sandstones may be argillaceous, silicious, calcareous, ferruginous, and other varieties according to the nature of the binding or cementing material. |
| Sedimentary | Shell | Stone composed largely of fossil shells, such as shell limestone, shell marble and shell marl. |

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* In part from Reference 6-5.

more than one million tons per year accounted for 37 percent of the total output, although only about 4 percent of the plants were in this size category.(6-3 to 6-5)

The most common type of crushed stone produced was limestone, which accounted for 74% of the total stone output in 1977. Granite and traprock contributed 11 and 8 percent of the total, respectively, for a combined share of 93% of the market for the three rock types. Major use of crushed stone was for roadbase (57%), concrete (13%) and cement (11%), with the remaining 19% being distributed for a large number of different uses as shown in Table 6-3.(6-3)

## Geology and Radionuclide Content

The major geologic rock types processed by the industry are sedimentary and igneous (Table 6-4). The radionuclide concentration in these types may vary considerably, dependent on their different geochemical histories. Certain generalizations can be made, however, based on the rock type. The radioactivity of igneous rocks for example is related to the quantity of silicates, being highest in acidic varieties and lowest in the ultrabasic.(6-6) Igneous rocks also generally exhibit higher radioactivity than sedimentary rocks while metamorphic types have concentrations similar to the unmetamorphosed rock from which they originate.(6-6) Certain sedimentary deposits such as phosphate rock or shale may have elevated radionuclide concentrations while others such as limestone are quite low.

Specific data on thorium and uranium levels in granitic rocks, from a study performed by Oak Ridge National Laboratories (6-7), are presented in Table 6-5. The data were obtained by measurement of radionuclide levels in about 180 rock samples from various parts of the United States. The object of the study was to determine the feasibility of extracting nuclear fuels (uranium and thorium) from relatively low-grade sources. Granitic rocks were chosen since they

## TABLE 6-3

### Crushed Stone Sold or Used by Producers in the United States, by Use[4]
(Thousand Short Tons and Thousand Dollars)

| Use | 1976 Quantity | 1976 Value | 1977 Quantity | 1977 Value |
|---|---|---|---|---|
| Roadbase aggregate | 191,160 | 401,710 | 220,590 | 494,150 |
| Other aggregate and roadstone | 131,170 | 299,880 | 156,250 | 367,370 |
| Concrete aggregate | 116,000 | 270,610 | 124,510 | 322,370 |
| Cement | 99,208 | 177,080 | 103,890 | 190,260 |
| Bituminous aggregate | 86,639 | 225,330 | 93,864 | 252,680 |
| Surface treatment aggregate | 54,708 | 131,670 | 44,920 | 111,630 |
| Lime 1/ | 37,756 | 88,474 | 36,363 | 89,065 |
| Aglime | 39,995 | 107,440 | 31,986 | 95,679 |
| Railroad ballast | 23,204 | 50,354 | 25,484 | 57,447 |
| Macadam aggregates | 27,556 | 61,356 | 25,307 | 56,384 |
| Flux stone | 23,767 | 57,621 | 23,067 | 59,049 |
| Riprap | 27,075 | 61,043 | 21,114 | 50,339 |
| Stone sand | 4,824 | 14,192 | 11,801 | 32,611 |
| Roofing granules | 4,394 | 11,798 | 5,099 | 14,702 |
| Fill | 4,993 | 8,656 | 4,608 | 6,629 |
| Other filler | 2,908 | 30,769 | 3,012 | 36,227 |
| Glass | 3,199 | 18,772 | 2,698 | 16,683 |
| Mineral food | 2,437 | 13,881 | 2,368 | 12,860 |
| Filter stone | 928 | 2,510 | 2,079 | 5,515 |
| Rock dust for coal mines | 1,377 | 8,026 | 1,337 | 8,463 |
| Asphalt filler | 832 | 4,478 | 1,131 | 5,234 |
| Refractory stone | 775 | 5,045 | 844 | 5,678 |
| Whiting | 976 | 19,726 | 833 | 21,711 |
| Sulfur dioxide removal | 655 | 1,496 | 807 | 1,962 |
| Terrazzo | 614 | 7,069 | 625 | 7,846 |
| Other Chemical | 1,095 | 1,877 | 615 | 1,048 |
| Agmarl | 469 | 1,468 | 559 | 1,903 |
| Lightwieght aggregate | 523 | 4,385 | 492 | 5,404 |
| Ferrosilicon | 1,007 | 2,814 | 339 | 1,402 |
| Acid neutralization | 27 | 173 | 295 | 1,071 |
| Abrasives | 98 | 706 | 157 | 1,048 |
| Paper | 136 | 656 | 116 | 412 |
| Building products | 122 | 282 | 62 | 131 |
| Bedding material | 135 | 391 | 61 | 238 |
| Drain fields | 323 | 448 | 30 | 63 |
| Waste products | 303 | 378 | W | W |
| Other uses 2/ | 8,929 | 24,098 | 6,640 | 17,727 |
| Total 3/ | 900,260 | 2,116,600 | 953,960 | 2,353,000 |

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W Witheld to avoid disclosing individual company confidential data, included with "Other uses."

1/Inclues dead-burned lime, alkalies, and sugar.

2/Includes magnesium metal, slate flour, poreclain, stucco, disinfectant, and uses indicated by symbol W.

3/Data may not add to totals shown because of independent rounding.

[4] Table from Refrence 6-3.

## TABLE 6-4

### Natural Radionuclides in Rocks*

| Type of Rock | Radionuclide Content<br>Potassium Percent | Uranium ppm | Thorium ppm |
|---|---|---|---|
| Igneous | | | |
| Silica (e.g., granites) | 3.3 | 4.7 | 20.0 |
| Intermediate (e.g., diorites) | 2.3 | 1.8 | 8.0 |
| Mafic (e.g., basalt) | 0.8 | 0.9 | 2.7 |
| Ultramafic (e.g, dunites) | 0.5 | 0.03 | 6.0 |
| Sedimentary | | | |
| Limestones | 0.3 | 2.2 | 1.7 |
| Carbonates | — | 2.1 | 1.9 |
| Sandstones | 1.2 | 1.5 | 3.0 |
| Shales | 2.3 | 3.5 | 11.0 |
| Mean Value (Earth's crust) | 2.3 | 3.0 | 11.4 |

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From Reference 6-6.

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## TABLE 6-5

Radionuclide Content of Selected Granitic and Related Rocks[a]

| Region/State | Sample Description/ Group /Area | Radionuclide Content - (ppm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Thorium | | | Uranium | | |
| | | Av. ±σ | Range | No.[b] | Av. ±σ | Range | No.[b] |
| I. New England | | | | | | | |
| A. New Hampshire | 1. Oliverian Magma Series | 24±12 | 6-51 | 12 | 6.3±4.1 | 3-14 | 11 |
| | 2. New Hampshire Magma Series | 23±27 | 1-109 | 23 | 4.7±3.4 | 1-16 | 23 |
| | 3. White Mountain Magma Series | 45±27 | 6-109 | 50 | 9.2±5.4 | 1-24 | 50 |
| B. Maine | Various | 28±17 | 11-88 | 25 | 6.1±2.5 | 3-12 | 25 |
| C. Massachusetts | Various | 26±19 | 10-69 | 9 | 4.1±2.5 | 1-9 | 9 |
| D. Rhode Island | Various | 35±21 | 16-68 | 8 | 4.5±4.0 | 1-14 | 8 |
| E. Connecticut | Various | 100±83 | 41-195 | 3 | 8.0±3.0 | 5-11 | 3 |
| II. Southeastern States | | | | | | | |
| A. Georgia | Elberton granodiorite | 45 | -- | 1 | 3 | -- | 1 |
| B. North Carolina/ Tennessee | Max Patch Granite | 22±30 | 6-98 | 9[c] | 2.2±1.3 | 1-5 | 8[d] |
| III. Central States | | | | | | | |
| A. Minnesota | Granite | 12 | | 1 | 5 | | 1 |
| B. Missouri | Missouri Red Granite | 40 | | 1 | 19 | | 1 |
| C. Oklahoma | Various | 15±4 | 10-20 | 7 | 3.6±1.4 | 2-6 | 7 |
| D. Texas | Enchanted Rock Batholith | 21 | | 1 | 4 | | 1 |

## TABLE 6-5 (cont'd)

Radionuclide Content of Selected Granitic and Related Rocks[a]

| Region/State | Sample Description/ Group /Area | Radionuclide Content - (ppm) Thorium Av. $\pm\sigma$ | Thorium Range | Thorium No.[b] | Uranium Av. $\pm\sigma$ | Uranium Range | Uranium No.[b] |
|---|---|---|---|---|---|---|---|
| IV. Western States | | | | | | | |
| A. Colorado | Various | 48±30 | 23-95 | 9 | 4.5±1.2 | 3-6 | 8 |
| B. Idaho | Pend - Oreille Area | 12±4 | 10-16 | 3 | 4.3±2.5 | 2-7 | 3 |
| C. Montana | Boulder Batholith Area | 16±8 | 7-31 | 9 | 3.4±1.8 | 2-7 | 9 |
| D. Washington/ S. British Columbia | Omak - Okanogan Valley Area | 6±5 | 2-16 | 6 | 2.2±1.5 | 1-4 | 6 |
| E. California | Mt. Whitney - Sierra Nevada Area | 19±9 | 6-26 | 6 | 4.5±1.0 | 4-6 | 4 |

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a From Ref 6-7. Samples obtained mostly from quarries.
b Number of samples analyzed.
c One value <5 ppm not included.
d One value <1 ppm not included.

exhibit a higher expectation value for radionuclide content than any other rock type. The areas sampled were also chosen on the basis of expected radionuclide content and thus could not be considered as representative of the state or region in which the samples were collected. The large majority of samples that were collected from stone quarries and analyzed indicate that the potential exists for the enhancement of natural radionuclides in the emissions from certain rock quarries.

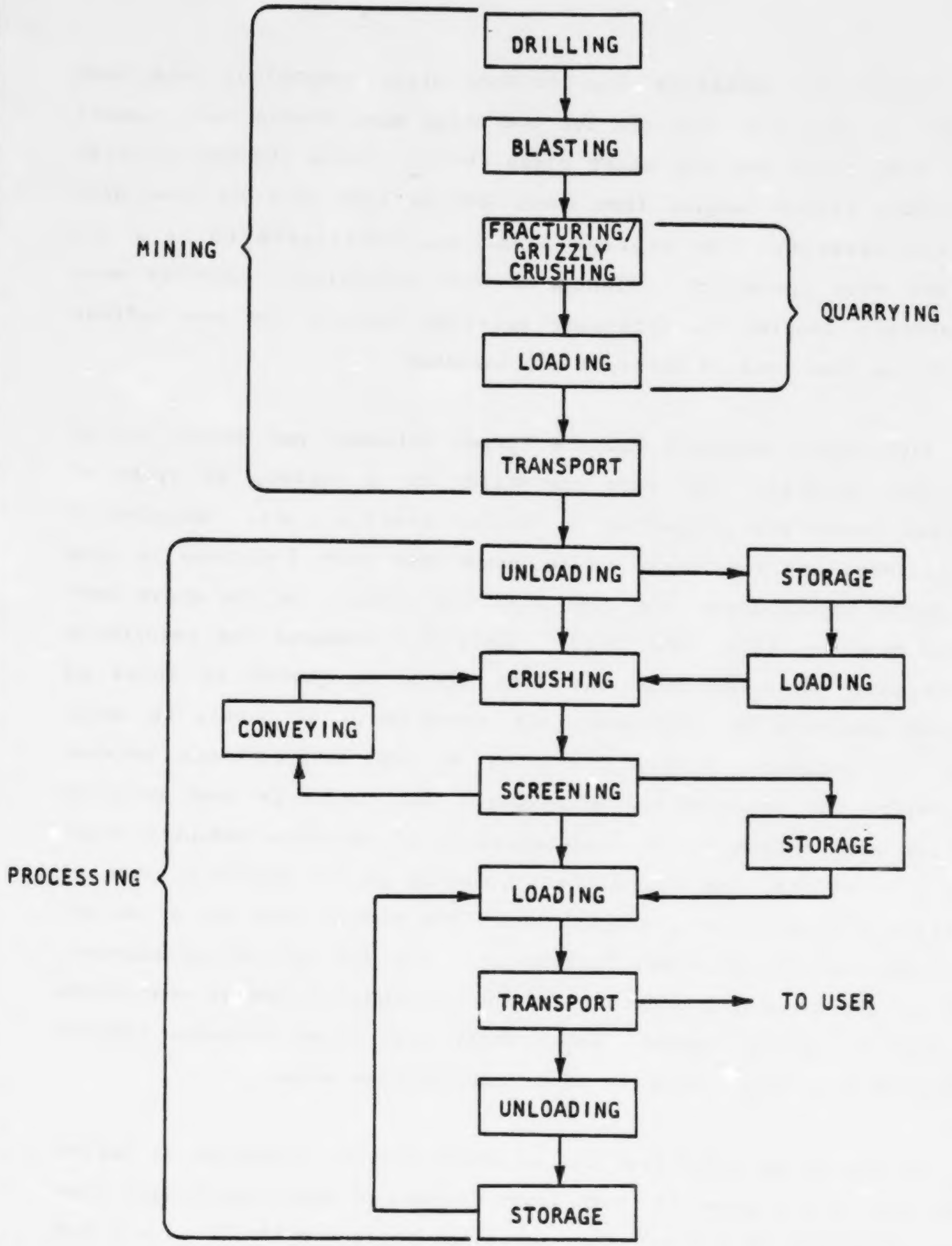
It should be noted that the largest quantity of rock produced is limestone. In general, radionuclide emissons from the stone industry should be somewhat less than average background levels (Table 6-4, mean value) due to the depleted, rather than enhanced, radionuclide contents of limestones relative to average background.

## Process Description

A generalized flowsheet of a crushed stone operation is shown in Figure 6.1. The major mining operations include drilling and blasting of the rock (usually very little overburden is involved), primary crushing and loading of the broken rock (quarrying), and transport to the processing area. The rock is then further crushed and screened to produce a range of desired product sizes from large riprap to fine manufactured sand. The various size products are stockpiled separately and ultimately loaded for transport to the customer.

## Airborne Radionuclide or Particulate Emissions

No data pertaining to the airborne emissions of radionuclides from various crushed stone operations could be found. Therefore a review of particulate emissions is presented as some qualitative correlations exist between airborne particulate releases and radioactive particulate emissions.


DRILLING
BLASTING
FRACTURING/ GRIZZLY CRUSHING
LOADING
TRANSPORT
MINING
QUARRYING
UNLOADING
STORAGE
CRUSHING
LOADING
CONVEYING
SCREENING
STORAGE
PROCESSING
LOADING
TRANSPORT
TO USER
UNLOADING
STORAGE

PRODUCTION OF CRUSHED STONE

Source: Ref. 6-8

FIGURE 6.1

Particulate emissions from crushed stone operations have been studied in detail by the EPA for the three most common rock classes (6-8, 6-9, 6-10) and one minor class.(6-11) These studies surveyed individual plants ranging from about 100 to 1000 tons per hour production capacity. An average plant was considered to be a 500 ton per hour operation. Plants of that approximate capacity were extensively sampled to determine emission factors for the various operations that produce airborne particulates.

Particulate emission factors (grams released per metric ton of processed material) for each operation for a variety of types of crushed stone are presented in Tables 6-6(a,b,c,d). Respirable particulates are considered to be those less than 7 microns in size and total particulates are less than 100 microns in the above mentioned studies. (6-8, 6-9, 6-10) Table 6-7 compares the respirable particulate emissions from the four stone categories in terms of percent contribution from each unit operation. It should be noted that the emission factors presented do not differentiate between controlled and uncontrolled emissions. The reason is that emission sources were chosen to be representative of standard industry practice. Therefore, operations that typically employ controls, such as drilling and vehicular transport which are always done wet or on wet surfaces, exhibit emission factors that are for controlled sources. Most of the remaining sources are usually uncontrolled or controlled to only a limited degree, hence their associated emission factors should be more representative of an uncontrolled souce.

It should be noted that the emission factors presented in Tables 6-6(a,b,c,d) are generally much lower (orders of magnitude lower) than those presented in a previously published reference.(6-11) Table 6-8 compares uncontrolled emission factors from the two references for five different operations performed in the crushed stone industry. The methods employed in the two studies to assess emissions differ substantially, hence the large discrepancies in the determined values.

# TABLE 6-6a

## Particulate Emissions: Crushed Limestone Industry

| Unit Operation | Particulate Emission Factor g/MT |  | Respirable Particulates | % Particulate Contribution from Unit Operation |  |
|---|---|---|---|---|---|
|  | Respirable | Total | % of Total | Respirable | Total |
| Drilling | 0.011 | 0.11 | 10 | 2 | 3 |
| Blasting | 0.013 | 0.075 | 17 | 2 | 2 |
| Loading at the quarry | a | 0.0015 | 0 | a | a |
| Vehicular traffic[b] | 0.23 | 2.3 | 10 | 39 | 66 |
| Primary crushing | 0.17 | 0.56 | 30 | 29 | 16 |
| Primary screening | 0.0005 | 0.0016 | 30 | a | a |
| Secondary crushing | 0.074 | 0.14 | 53 | 12 | 4 |
| Secondary screening | 0.0005 | 0.0009 | 53 | a | a |
| Conveying | 0.096 | 0.32 | 30 | 16 | 9 |
| Stockpiles | a | a | a | a | a |
| Unloading at stockpiles | a | a | a | a | a |
| TOTAL[c] | 0.60 | 3.5 | 17 | 100 | 100 |

---

[a] Negligible.
[b] On unpaved road between quarry and plant.
[c] Total may not add to figure shown due to rounding.

## TABLE 6-6b

### Particulate Emissions: Crushed Granite Industry

| Unit Operation | Particulate Emission Factor g/MT | | Respirable Particulates | % Particulate Contribution from Unit Operation | |
|---|---|---|---|---|---|
| | Respirable | Total | % of Total | Respirable | Total |
| Drilling | 0.040 | 0.399 | 10.0 | 0.3 | 0.4 |
| Blasting | 13.5 | 79.6 | 16.9 | 88.8 | 74.4 |
| Loading onto haul trucks | a | a | a | a | a |
| Dumping to primary crusher | 0.008 | 0.21 | 3.6 | 0.1 | 0.2 |
| Primary crusher | a | a | a | a | a |
| Secondary crushing and screening | 0.79 | 22 | 3.6 | 5.2 | 20.6 |
| Conveying | a | a | a | a | a |
| Unloading to stockpiles | a | a | a | a | a |
| Loading from stockpiles | a | a | a | a | a |
| Vehicular movement on dry unpaved roads | 0.86 | 4.91 | 17.6 | 5.7 | 4.6 |
| Windblown emissions | a | a | a | a | a |
| TOTAL[b] | 15.3 | 107 | 14.3 | 100 | 100 |

---

[a] Negligible.
[b] Data may not add to totals due to independent rounding.

## TABLE 6-6c

Particulate Emissions: Crushed Sandstone, Quartz, and Quartzite Industry

| Unit Operation | Particulate Emission Factor g/MT | | Respirable Particulates | % Particulate Contribution from Unit Operation | |
|---|---|---|---|---|---|
| | Respirable | Total | % of Total | Respirable | Total |
| Drilling | 0.009 | 0.05 | 18 | 0.24 | 0.15 |
| Blasting | 0.003 | 0.56 | 0.5 | 0.08 | 1.65 |
| Loading | 0.0006 | 0.012 | 5.0 | 0.01 | 0.04 |
| Unloading | 0.05 | 0.13 | 38 | 1.41 | 0.4 |
| Washing and screening | 0.84 | 7.6 | 11 | 24 | 22.37 |
| Crushing | 1.34 | 13.4 | 10 | 38.41 | 39.44 |
| Conveying | 0.11 | 1.73 | 6.4 | 3.2 | 5.1 |
| Transport on unpaved roads | 0.74 | 4.1 | 18 | 21.21 | 12.1 |
| Stockpiles | 0.4 | 6.4 | 6.2 | 11.43 | 18.83 |
| TOTAL[a] | 3.6 | 34.7 | 10 | 100 | 100 |

---

[a] Data may not add to totals due to rounding.

## TABLE 6-6d

Particulate Emissions: Other Crushed Stone Industries (traprock, marl, shell marble, slate, and other miscellaneous stone)

| Unit Operation | Particulate Emission Factor g/MT | | Respirable Particulates | % Particulate Contribution from Unit Operation | |
|---|---|---|---|---|---|
| | Respirable | Total | % of Total | Respirable | Total |
| Blasting | 0.0088 | 0.0522 | 17 | 0.27 | 0.18 |
| Drilling (wet) | 0.0160 | 0.158 | 10 | 0.49 | 0.56 |
| Quarrying | 1.050 | 10.500 | 10 | 32.3 | 37.02 |
| Primary crushing and loading | 1.340 | 13.400 | 10 | 41.2 | 47.2 |
| Secondary crushing and screening | 0.342 | 0.619 | 55 | 10.5 | 2.18 |
| Tertiary crushing and screening | 0.0665 | 0.362 | 18 | 2.05 | 1.28 |
| Fines crushing and screening | 0.0147 | 0.0918 | 16 | 0.45 | 0.32 |
| Conveying | 0.113 | 1.730 | 7 | 3.48 | 6.10 |
| Loading trucks | 0.0453 | 0.166 | 68 | 1.39 | 0.58 |
| Unloading trucks | 0.0538 | 0.127 | 42 | 1.65 | 0.45 |
| Transport (wet) | 0.202 | 1.150 | 18 | 6.21 | 4.05 |
| TOTAL[a] | 3.250 | 28.400 | 11 | 100 | 100 |

---

[a] Data may not add to totals due to rounding.

## TABLE 6-7

### Respirable Particulate Emissions - Crushed Stone Industry
(Percent Contribution From Unit Operations)

| | Limestone | Granite | Sandstone Quartz Quartzite | Other Crushed Stone |
|---|---|---|---|---|
| Drilling | 2 | 0.3 | 0.2 | 0.3 (wet) |
| Blasting | 2 | 88.8 | 0.1 | 0.5 |
| Quarrying - Fracturing | | | | |
| Grizzly Crushing | | | | [32.3] |
| Loading | (d) | (d) | (d) | |
| Transport (b) | 39 | | | |
| Unloading | | 0.1 | 1.4 | (a) |
| Washing | | | [24.0] | |
| Screening | | | | |
| Primary Crushing | 29 | (d) | 38.4 | 41.2 (a) |
| Primary Screening | (d) | | | |
| Secondary Crushing | 12 | [5.2] | | [10.5] |
| Secondary Screening | (d) | | | |
| Tertiary Crushing | | | | [2.0] |
| Tertiary Screening | | | | |
| Fines Crushing | | | | [0.4] |
| Conveying | 16 | (d) | 3.2 | |
| Stockpiles - Unloading | (d) | (d) | | 3.5 |
| Storage (c) | (d) | | 11.4 | 1.6 |
| Loading | | (d) | | |
| Transport (b) | | 5.7 | 21.2 | 1.4 |
| Windblown Emissions (c) | | (d) | | 6.2 (wet) |
| Total - Percent | 100 | 100 | 100 | 100 |
| - Emission Factor in g/metric ton | 0.60 | 15.3 | 3.6 | 3.2 |

---

(a) Combined emission factor, primary crushing and unloading.

(b) Vehicle transport, generally on unpaved roads. Appears twice to show order presented in Tables 66 (a-d), although the measured emission factors for the various transporting operations are usually combined to reflect all transport operations.

(c) As in footnote (b), listed separately to reflect order of presentation, but are essentially the same.

(d) Negligible.

| | Indicates combined emission factor for bracketed operations.

## TABLE 6-8

Crushed Stone Industry - Emission Factors Obtained From Two Studies[a]

| Operation | Reference 6-11 Total Particulate Emissions g/MT | Reference 6-11 % Suspended Emissions | Reference 6-11 Suspended Emissions g/MT | Reference 6-9 Total Particulate Emissions g/MT | Reference 6-9 % Respirable Emissions | Reference 6-9 Respirable Emissions g/MT |
|---|---|---|---|---|---|---|
| Primary crushing | 250 | 20 | 50 | 13 | 10 | 1.3 |
| Secondary crushing and screening | 750 | 40 | 300 | 1 | 55 | 0.6 |
| Tertiary crushing and screening | 3,000 | 60 | 1,800 | 0.4 | 18 | 0.1 |
| Fines milling | 3,000 | 75 | 2,250 | 0.1 | 16 | 0.2 |
| Recrushing and screening | 2,500 | 50 | 1,250 | b | b | b |
| TOTAL | 9,500 | 59 | 5,650 | 14.5 | 15 | 2.2 |

---

a Uncontrolled emission factors.
b No data reported.

One major difference was that the initial studies attempted to measure the influent and effluent concentrations from stacks. The latter study measured airborne concentrations around the contributing source. Hence, the sampling method outlined in the references on which Tables 6-6(a,b,c,d) and 6-7 are based are considered by the authors to yield much more realistic estimates of emissions than previously reported. A more thorough discussion comparing the sampling methods and results is presented in reference 6-9.

The major emission points vary depending on the type of stone processed due to the different degrees and types of operations involved. In general, stone crushing and vehicular transport on unpaved roads emit 60% to 80% of the respirable particulates, the remaining emission contributions being distributed among the other activities. A major exception is seen in the crushed granite industry, where almost 90% of the respirable particulates are emitted in the blasting operation.

## Airborne Radionuclide or Particulate Emission Controls

No data could be found concerning the control of airborne emissions of radionuclides from crushed stone operations. Control of airborne particulate releases is therefore discussed, the assumption being that particulate controls also limit particulate radionuclide emissions.

Essentially the only control used to reduce dusting from vehicular traffic on unpaved roads is through periodic spraying with water or oil. Particulate emission control technology employed by the crushed stone industry is limited primarily to two main types, wet dust suppression of fugitive and process sources and fabric filters for dust collection at processing points.

Process sources (e.g., crushing, screening, conveying and transfer) may be controlled by wet suppression, fabric filters, or a combination of the two.

A study by the Bureau of Mines (1974) reviewed the methods and cost of dust control in model stone crushing operations of 300, 600 and 1000 tons per hour.(6-13) A portion of the study is presented in Table 6-9. Particulate collection efficiency is not presented in the table as it approaches 95% by weight for all the systems. Also discussed were the major advantages and disadvantages of the systems. These are reproduced in Table 6-10.

A combination system is used if both product recovery and fine screening are required. Also, fabric filter systems alone are impractical when dust collection points are numerous and plant layout is not conducive to cost-effective installation. All three approaches are discussed in greater detail in the reference document.

The effectiveness of a fabric filter system in removing fine particles in the respirable or transportable size range was also discussed in reference 6-9. The authors took the uncontrolled emission factor of 9500 grams per metric ton of stone processed, as was determined by sampling dust loadings at fabric filter inlets, and applied a collection efficiency of 99.8% for the fabric filter. The resulting controlled emission factor was very nearly equal to the uncontrolled emission factor of 14.5 g/MT reported by the authors as determined by sampling air concentrations around the source. The significance of this observation is that it implies that the fabric filter system does little to reduce the air transportable emissions capable of leaving the plant boundaries. Thus the bulk of the uncontrolled emissions, as reported by this reference, are not transportable and hence do not contribute to off-site ambient air concentrations. Fabric filters merely collect the dust that would settle out within the plant boundaries.

## TABLE 6-9

Particulate Control Systems - Costs and Requirements[a]

| Control System[b] | Total Installation Costs | Annual Operating Costs | Annual Energy Use (kw-hr) | Annual[c] Water Use (gallons) | Air Requirement (CFM) |
|---|---|---|---|---|---|
| 1] Wet Suppression | | | | | |
| 300 tph | 49,130 (64,950)[d] | 8,394 (11,090)[d] | 2,900 | 345,600 | --- |
| 600 tph | 59,390 (78,510) | 12,389 (16,380) | 7,200 | 691,200 | --- |
| 1000 tph | 71,906 (95,100) | 17,050 (22,540) | 7,200 | 1,152,000 | --- |
| 2] Fabric Filter | | | | | |
| 300 tph | 105,886 (139,990) | 18,684 (24,700) | 202,100 | --- | 48,000 |
| 600 tph | 168,847 (223,220) | 29,780 (39,370) | 377,700 | --- | 82,000 |
| 1000 tph | 249,162 (329,390) | 46,606 (61,610) | 553,400 | --- | 124,000 |
| 3] Combination System | | | | | |
| 300 tph | 89,806 (118,730) | 14,521 (19,200) | 72,700 | 230,400 | 16,500 |
| 600 tph | 111,863 (147,880) | 20,054 (26,510) | 117,300 | 460,800 | 25,000 |
| 1000 tph | 136,338 (180,241) | 29,308 (38,740) | 182,100 | 768,000 | 36,000 |

---

[a] From Ref 6-13. Costs presented are in 1974 dollars.

[b] Data are presented for three plant production rates, in short tons per hour (tph) of crushed stone.

[c] Wet suppression system used approximtely 40% of production time.

[d] Bracketed numbers are updated to 1978 dollar value.

## TABLE 6-10

Comparison of Two Methods of Dust Control in Stone Crushing Operations

| System | Advantages | Disadvantages |
|---|---|---|
| Fabric Filter System | Collected dust can be recovered, allowing for reuse or sale. Clogging of fine-meshed screens is avoided. | Collected dust incurs disposal cost if not usable or soluble. Costs more to install and operate than a wet dust suppression system. |
| Wet Suppression System | No waste disposal problem. Costs less than fabric filter system. Easier to operate than fabric filter system. | May be unusable in fine screening or fine crushing stages due to screen clogging or crusher packaging problems. Stone washing and settling facilities must be added if the stone product is used to make concrete. |

## The Iron Industry

The making of iron and steel can be considered to be a two step process. The first of these consists of the mining and beneficiation of iron ore to produce usable iron-bearing material. The second step consists of the processing of this material to produce pig iron, raw steel, and a variety of finished iron and steel products. These processing steps will be considered separately.

### A. Iron Ore

#### Industry Description

The iron ore industry is the fourth largest mining industry in the U.S. in terms of quantity of material mined.(6-14) Total output of crude ore (23% average iron content by weight) was 220 million long tons in 1978 (6-15), more than 98% of which was beneficiated to produce 80 million long tons of usable ore (62% average iron content, by weight). Open pit mines accounted for 97% of the usable ore production, thus requiring the removal of a substantial amount of overburden. Stripping ratios, or tons of overburden removed per ton of crude ore mined, vary from mine to mine. Applying the average ratio for 1977 (approximately 1 to 1) to the total 1978 ore production results in an estimate of 220 million long tons of overburden removed.

In 1977, 34 companies operated 50 iron mines, 45 concentration plants, and 22 pelletizing plants. The industry, although distributed nationwide, is centered in the Lake Superior District iron mining region. Three states in this region (Minnesota, Michigan, and Wisconsin) accounted for approximately 80% of the entire Nation's output of usable ore, with Minnesota alone accounting for 56%. Furthermore, 8 companies operating 18 mines produced 85% of the total output. (6-16)

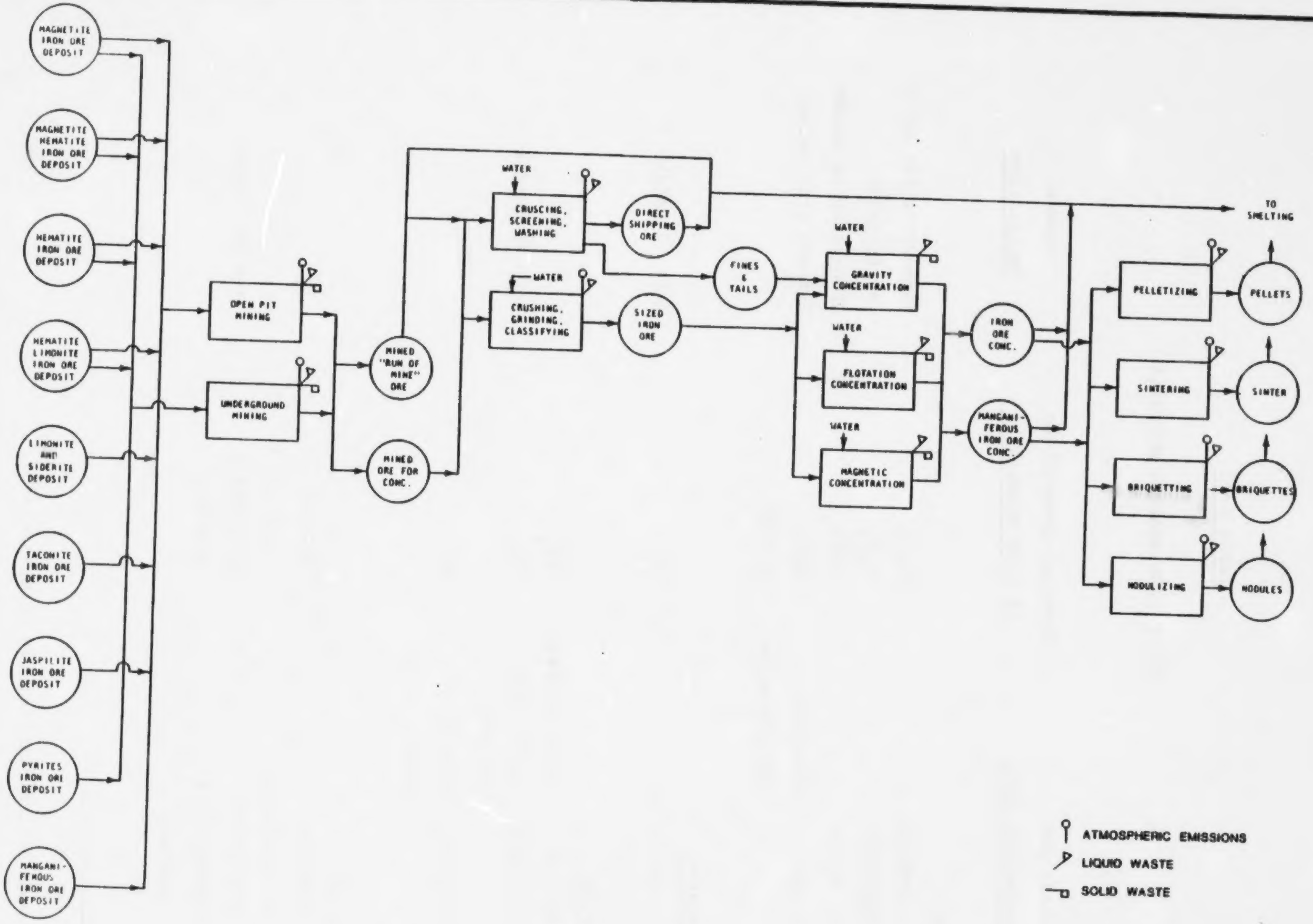
A general flow diagram of the iron ore industry is shown in Figure 6.2. Beginning with the ores most commonly mined, the diagram indicates the various processing alternatives employed in the production of iron and steel making feed material. This may be generalized as mining, concentrating and agglomerating.

The trend in recent years has been towards beneficiation of iron ores regardless of ore grade. Whereas in 1952 less than half of all iron ore was beneficiated, in 1978 the amount was over 98%, with 80% of the total being agglomerated, practically all in the form of pellets.(6-15). The main reason for this trend is the demand for high grade blast furnace feed, with strict requirements for uniform chemical composition and physical characteristics, and high iron content.

Pellets produced from taconite ores account for most blast furnace feed. The taconite industry is centered on the Mesabi iron range in Minnesota. Eight pellet plants shipped an estimated 50 million long tons of pellets from that range in 1978. Plant expansions, scheduled for completion by 1980, will result in pellet production capacities of 64.2 million long tons for the Mesabi range, (6-18) or almost 70% of the entire U.S. capacity of 94 million long tons of pellets.(6-19)

## Ore Geology and Radionuclide Content

Iron is the fourth most common element in terms of crustal abundance (5% by weight). It is associated with a large number of minerals, only a few of which are of commercial importance. These are listed in Table 6-11 by mineral class. The class most widely mined for its iron content is the oxide group. Within this group, magnetite accounted for 80% of the crude iron ore mined in the United States in 1975 (6-16), followed by hematite (19%), and limonite (1%). Furthermore, supplies of high-grade (natural) ores have all but been exhausted, resulting in large scale mining of low-grade ores which are generally referred to as taconite type ores.


MAGNETITE IRON ORE DEPOSIT
MAGNETITE HEMATITE IRON ORE DEPOSIT
HEMATITE IRON ORE DEPOSIT
HEMATITE LIMONITE IRON ORE DEPOSIT
LIMONITE AND SIDERITE DEPOSIT
TACONITE IRON ORE DEPOSIT
JASPILITE IRON ORE DEPOSIT
PYRITES IRON ORE DEPOSIT
MANGANI-FEROUS IRON ORE DEPOSIT
OPEN PIT MINING
UNDERGROUND MINING
MINED "RUN OF MINE" ORE
MINED ORE FOR CONC.
WATER
CRUSCING, SCREENING, WASHING
WATER
CRUSHING, GRINDING, CLASSIFYING
DIRECT SHIPPING ORE
SIZED IRON ORE
FINES & TAILS
WATER
GRAVITY CONCENTRATION
WATER
FLOTATION CONCENTRATION
WATER
MAGNETIC CONCENTRATION
IRON ORE CONC.
MANGANI-FEROUS IRON ORE CONC.
TO SMELTING
PELLETIZING
SINTERING
BRIQUETTING
NODULIZING
PELLETS
SINTER
BRIQUETTES
NODULES
ATMOSPHERIC EMISSIONS
LIQUID WASTE
SOLID WASTE

FLOW DIAGRAM
IRON ORE MINING, BENEFICIATION, AND AGGLOMERATION
(SOURCE: FROM REFERENCE 17)

## Table 6-11

## CHIEF IRON-BEARING MINERALS

| Class and Mineralogical Name | | Chemical Composition of Pure Mineral | Common Designation |
|---|---|---|---|
| **Oxide**[b] | | | |
| Magnetite | | $Fe_3O_4$ | Ferrous-ferric oxide |
| Hematite | | $Fe_2O_3$ | Ferric oxide |
| Ilmenite | | $FeTiO_3$ | Iron-titanium oxide |
| Limonite | Goethite | $HFeO_2$ | Hydrous iron oxides |
| | Lepidocrocite | $FeO(OH)$ | |
| **Carbonate** | | | |
| Siderite | | $FeCO_3$ | Iron carbonate |
| **Sulphide** | | | |
| Pyrite | (iron pyrites) | $FeS_2$ | Iron Sulphides |
| Marcasite | (white iron pyrites) | $FeS_2$ | |
| Pyrrhotite | (magnetic iron pyrites) | $FeS$ | |
| **Silicate** | | | |
| Chamosite | | Various and sometimes complex | Iron Silicates |
| Stilpnomelane | | | |
| Greenalite | | | |
| Minnesotaite | | | |
| Grunerite | | | |

---

[a] Based on information from Reference 6-20.

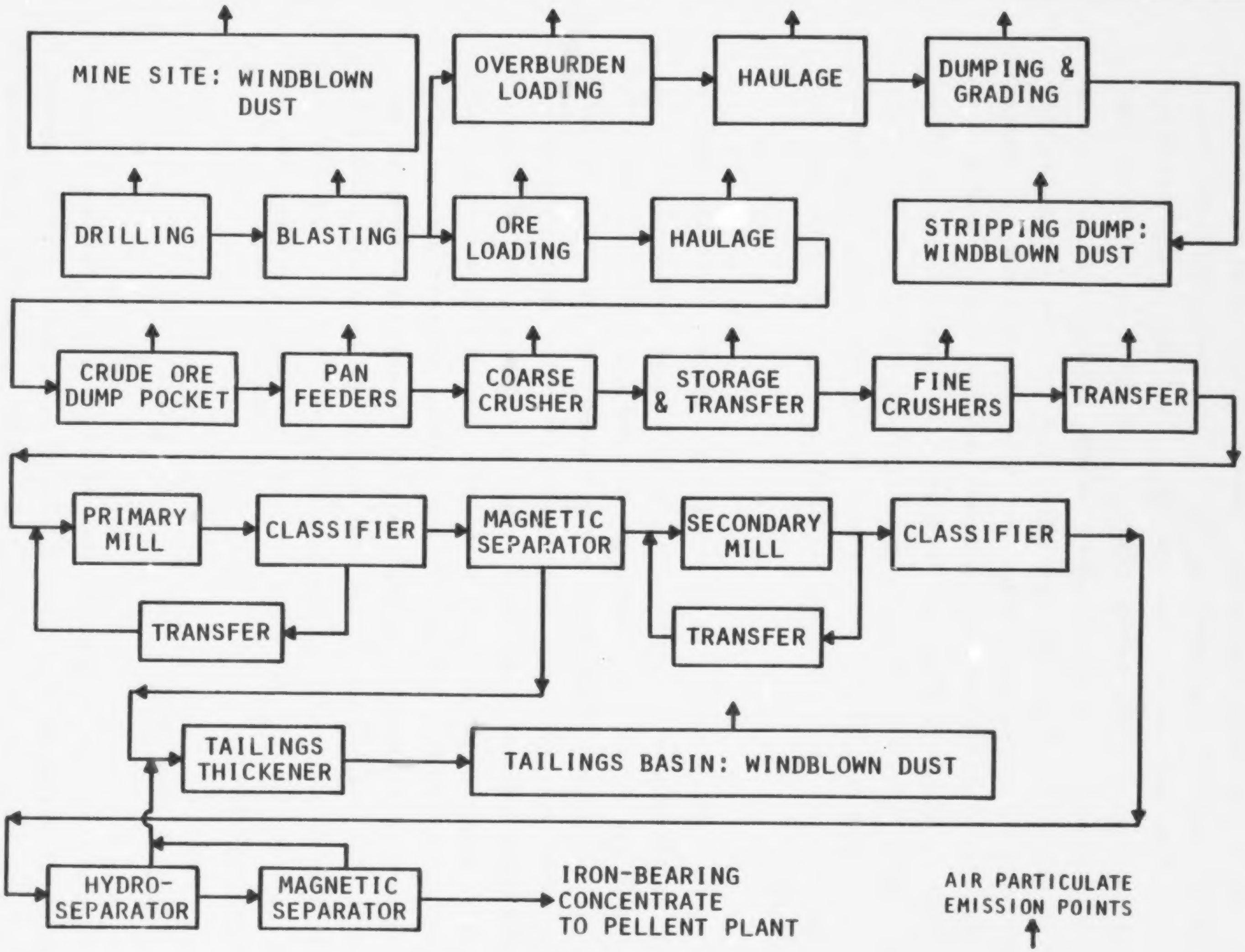
[b] Low grade oxide ores are generally referred to as taconite.

An intensive literature search and industry survey failed to yield any data regarding the concentration of natural radionuclides in iron ore or associated overburden. Some data does exist on the radon daughter concentrations found in the air of underground iron mines. (6-21) Mine sampling by the Mine Safety and Health Administration (MSHA) in the 1975-1977 period revealed that three out of seven mines examined had radon daughter concentrations greater than 0.3 working levels (WL), with a maximum reading of 0.9 WL. The average working level for all non-uranium mines was 0.14 WL (excluding an exceptionally high phosphate mine), whereas uranium mines averaged 0.58 WL.(6-22) Conclusions cannot be drawn from this information, however, since elevated radon daughter concentrations in underground mines are not necessarily associated with the ore body. Radiometric analysis of the ores would be required, and this, to date, has not been done.

Prediction of the range of uranium and progeny concentrations in iron ore based upon the geochemical properties of iron and uranium is difficult due to uncertainties as to how some iron deposits form. For example, it is not known whether the Precambrian Lake Superior District iron formations were deposited by biogenic, clastic deposition or chemical precipitation means prior to any weathering or metamorphism. Although it is known that these deposits were formed under relatively reducing conditions and uranium is precipitated from solution under reducing conditions, it is not known whether the depositional environment of the iron formations is at all related to that of uranium deposits in the Lake Superior District. The issue of the radionuclide concentration of iron ore will therefore not be further addressed.

## Process Description

A general flow diagram of open pit iron mining and ore concentrating is presented in Figure 6.3.(6-23) A large number of operations are involved, and many of them result in airborne particulate


MINE SITE: WINDBLOWN DUST
OVERBURDEN LOADING
HAULAGE
DUMPING & GRADING
DRILLING
BLASTING
ORE LOADING
HAULAGE
STRIPPING DUMP: WINDBLOWN DUST
CRUDE ORE DUMP POCKET
PAN FEEDERS
COARSE CRUSHER
STORAGE & TRANSFER
FINE CRUSHERS
TRANSFER
PRIMARY MILL
CLASSIFIER
MAGNETIC SEPARATOR
SECONDARY MILL
CLASSIFIER
TRANSFER
TRANSFER
TAILINGS THICKENER
TAILINGS BASIN: WINDBLOWN DUST
HYDRO-SEPARATOR
MAGNETIC SEPARATOR
IRON-BEARING CONCENTRATE TO PELLENT PLANT
AIR PARTICULATE EMISSION POINTS

(SOURCE: REF. 6-9)

AIR PARTICULATE EMISSION POINTS-TACOMITE ORE MINING AND BENEFICIATION

DAMES & MOORE

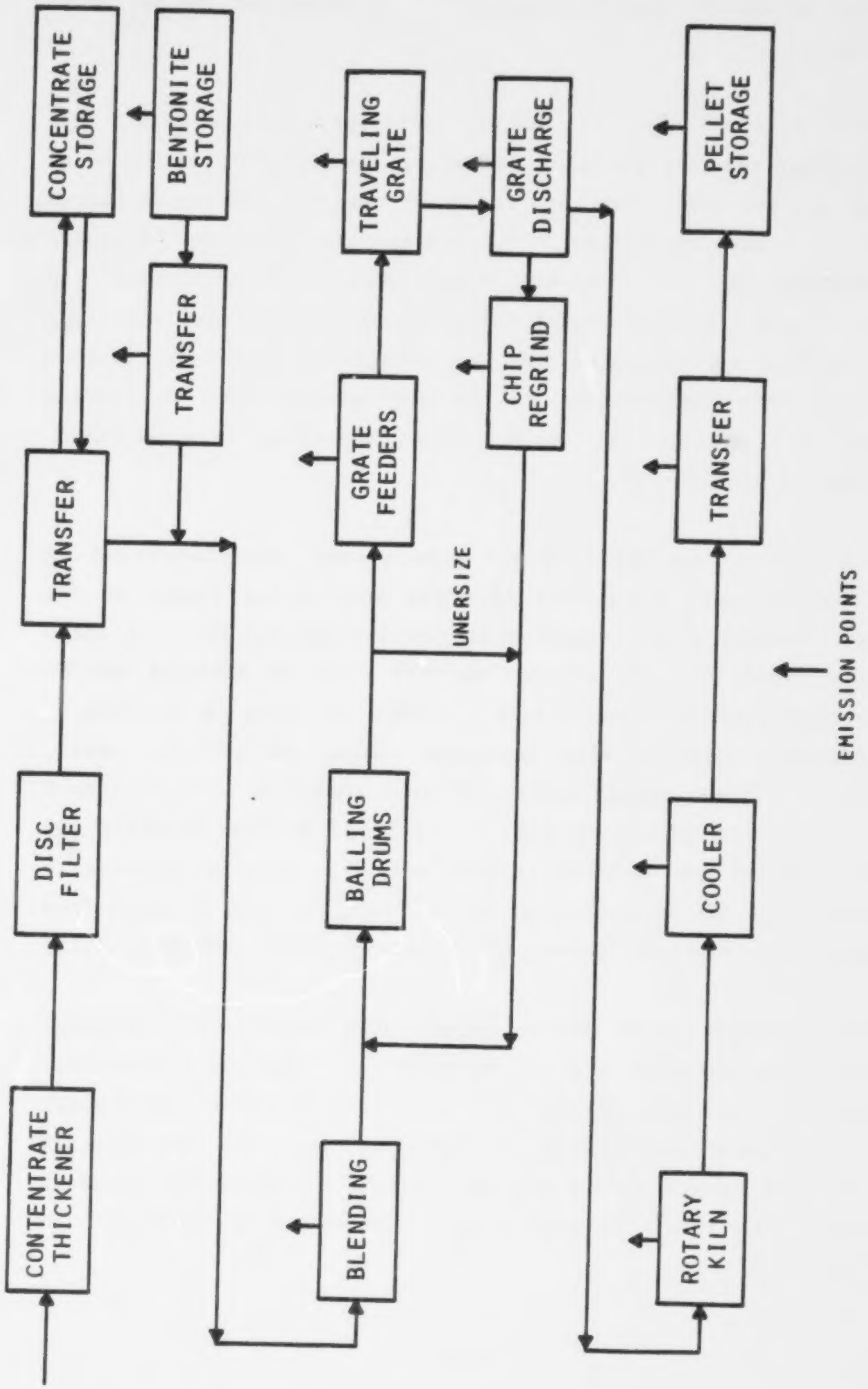
FIGURE 6.3

emissions. A similar diagram (Figure 6.4) is shown for the pelletizing process.

Essentially all open pit mining operations produce dust. The primary operations are drilling, blasting, and loading of loose or broken up ore and overburden into trucks or trains. The ore is hauled to a nearby crusher and dumped into a bin and the overburden is hauled to a stripping dump for later use in land reclamation activities. In addition to these activity-related dust sources, windblown dust from the mining site and stripping dump can contribute to the particulate emissions. This contribution can be substantial since an average operation (2.5 million ton annual pellet capacity) requires about 5,000 acres of land.(6-19)

The crude ore is fed from the dump pocket into the crushing circuit, which usually consists of three succcessive stages of dry crushing. Various size classification (screening) and transfer steps are incorporated into the circuit so that oversize material may be re-crushed and undersize may bypass a stage. Crushing is followed by a wet grinding circuit, also including sizing and transfer steps, resulting in a finely ground mixture of iron mineral grains and gangue material which are then separated to yield pellet feed material and tailings. United States taconite ores generally require grinding to 90 percent minus 325 mesh in order to liberate the iron minerals from the gangue, and some are ground to 95 percent minus 500 mesh.(6-19)

Mineral separation is usually accomplished magnetically, although froth flotation circuits are in operation and usage is increasing. Both are wet processes and do not result in airborne particulate emissions. Gangue material is thickened and sent to the tailings basin, and the iron minerals may be further processed for enhanced separation. The resulting iron-bearing concentrate is then sent to the pellet plant.


CONTENTRATE THICKENER
DISC FILTER
TRANSFER
CONCENTRATE STORAGE
BENTONITE STORAGE
TRANSFER
BLENDING
BALLING DRUMS
UNERSIZE
GRATE FEEDERS
TRAVELING GRATE
GRATE DISCHARGE
CHIP REGRIND
ROTARY KILN
COOLER
TRANSFER
PELLET STORAGE
EMISSION POINTS

(SOURCE: REF. 6-23)

PELLETIZER FLOWCHART

FIGURE 6.4

The concentrate is thickened, filtered to remove water, and blended with a small amount of binding material (usually bentonite). This mixture, containing 9 to 10 percent moisture, is processed in rotating drums (or disks) to produce small round pellets, usually between 3/8 and 1/2 inch in diameter. The pellets are then hardened by drying and heating to about 2400°F in an oxidizing atmosphere for several minutes. The systems usually employ a horizontal furnace with a traveling grate that holds the pellets. The hardened pellets are then cooled and transferred to a storage area to await final transport to iron and steelmaking centers.

## Airborne Particulate Releases

Airborne radionuclide emissions, if any, would be those associated with particulate releases. An extensive study of airborne particulate emissions from iron ore mining and processing has recently been performed for the EPA.(6-23) The results of the study presented a comprehensive review of this subject. Hence, much of the material presented in this section is based on that study. The most important aspects of each emission source are listed below.

### Mine Sources

Blasthole drilling - A relatively insignificant source. Water is used in rotary drilling for dust suppression and cooling. Spalled chips produced by jet piercing drills are removed by steam generated from cooling water.

Blasting - A minor, intermittent source. Most of the airborne material consists of large particles that settle out rapidly. This source is not easily controlled, however.

Material loading - A continuous operation, generating large amounts of airborne particulates. Shovel loading generates less dust than shovel unloading (dumping). Ore particles are the primary emissions, since waste rock and overburden operations do not seem to generate significant amounts of dust.

Haulage roads - Haulage vehicles traversing unpaved roads are a major source of fugitive emissions.

Windblown dust - Dust is generated by wind action on barren mine surfaces and waste piles. This source can be significant due to the large areal extent of some operations. Dusting from tailings basins can be significant due to the generally fine particle size.

### Processing Sources

Crude ore dump pocket - The vehicle unloading operation may be a significant source.

Pan feeders - Crude ore is fed from the dump pocket to the coarse crusher. This transfer operation produces some dusting.

Coarse crushing - This is generally a dry operation and represents a significant source of ore dust.

Ore transfer - Transferring of ore, usually by conveyor belt, involves material exchange between the conveyor and the process input or output, or between conveyors. Significant emissions may result.

Fine crushing - A significant source. Multiple crushers are usually employed to reduce the ore to the particle size range desired for mill feed. Screening (sizing) operations are usually incorporated to recirculate oversized material back into the crushers (closed circuit).

Milling (fine grinding and classifying) - This is generally a wet operation and hence is not an important source of emissions.

Mineral separation - Magnetic separation and froth flotation are wet processes and do not contribute to emissions.

Concentrate thickening, filtering, transfer and storage - Concentrate remains moist and no dust is produced.

Bentonite transfer - Bentonite dust is emitted during handling operations. The radiological significance of these emissions would depend on any natural radioactivity associated with the bentonite.

Bentonite blending - The beneficiated ore concentrate remains moist, hence concentrate dust is not generated when it is blended with the bentonite.

Balling drums - Ore concentrate/bentonite mixture remains moist, producing little dusting.

Grate feeders - Green pellets are fed into the furnace grate, resulting in some emissions.

Grate discharge - Pellets are transferred from the furnace grate, resulting in emissions. Straight grate furnaces cool the pellets while on the grate, recirculating the heated air back to the initial drying and heating stages of the grate. The traveling grate emits some particulates, but this is minor compared to the grate end-points. Grate-kiln systems transfer the pellets from the traveling grate to a rotary kiln for induration.

Rotary kiln - This system tumbles the pellets during induration while a large volume of air moves countercurrently through the system. This results in a heavily particulate laden gas exiting the system, referred to as the main waste gas stream. There is a possibility that Polonium-210 could be volatized in this process if uranium and its daughters are present.

Pellet cooling - Hot pellets are dumped from the rotary kiln into an annular cooler. Significant emissions are generated when upward flowing cooling air picks up the dust produced by the autogenous grinding action of the kiln. Some of this air is ducted back into the kiln and some is directly exhausted through a stack.

Pellet handling - Cooled pellets are transferred to a loadout point, where they are stockpiled or loaded directly into rail cars for shipment. Dusting occurs during these handling operations.

Pellet storage - Pellet stockpiles can contribute to fugitve emissions to a varying degree.

Other sources - Fugitive emissions from other sources can vary greatly in importance from plant to plant. Examples include the return side of conveyors and excess dust due to ineffective use of scavenger-type dust controls.

Emission data were collected from a variety of sources for ten of the above process emission points considered to be representative of the taconite processing industry. These data are summarized in Table 6-12, which presents both controlled and uncontrolled emissions from each point source in terms of kilograms of particulates emitted per metric ton of pellets produced, plus the percent of total emissions contributed by that source. The effective control efficiencies are also shown. The emission points are presented in the order found in the process flow sheets. In the case of fine crushing, data pertaining to dry autogenous grinding (employed on a limited basis in the industry) are included in this category.

## Airborne Radionuclide or Particulate Emission Controls

Detailed fugitive emission control data was not presented in the reference report due to its inavailability. Generally, water is

Pellet cooling - Hot pellets are dumped from the rotary kiln into an annular cooler. Significant emissions are generated when upward flowing cooling air picks up the dust produced by the autogenous grinding action of the kiln. Some of this air is ducted back into the kiln and some is directly exhausted through a stack.

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Airborne Radionuclide or Particulate Emission Controls

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## TABLE 6-12

## Point Source Particulate Emissions

| Source | Particulate Emission Rate[b] | | | | Control Efficiency[c] |
|---|---|---|---|---|---|
| | Uncontrolled | | Controlled | | |
| | kg/MT | % of Total | kg/MT | % of Total | % |
| Crude ore dump pocket | 0.44 | 0.8 | 0.07 | 9.8 | 84.1 |
| Coarse crushing | 0.10 | 0.2 | 0.006 | 0.8 | 94.0 |
| Ore transfer | 0.05 | 0.1 | 0.001 | 0.1 | 98.0 |
| Fine crushing | 39.9 | 68.9 | 0.18 | 25.1 | 99.5 |
| Bentonite transfer | 0.02 | 0 | <0.001 | <0.1 | >95.0 |
| Bentonite blending | 0.11 | 0.2 | <0.001 | <0.1 | >99.1 |
| Grate feed | 0.32 | 0.6 | 0.004 | 0.6 | 98.8 |
| Grate discharge | 0.66 | 1.1 | 0.005 | 0.7 | 99.2 |
| Waste gas | 14.6 | 25.2 | 0.44 | 61.5 | 97.0 |
| Pellet handling | 1.7 | 2.9 | 0.008 | 1.1 | 99.5 |
| Total | 57.9 | 100 | 0.715 | 100 | 98.8 |

---

[a] Based on data from Reference 6-23.

[b] Kilograms of particles emitted per metric ton of pellets produced. Percent contribution of each source to total emissions have been rounded to nearest tenth percent.

[c] Control efficiency based on controlled and uncontrolled emission rates.

used to suppress emissions from drilling operations, but control efficiencies are unknown. Dusting from unpaved haulage roads is suppressed by sprinkler truck application of water, but this method cannot be used in the winter, and frequent application is required. Emissions from blasting operations are generally controlled procedurally, such as blasting when the meteorological conditions help to minimize dusting. Loading of haulage vehicles is uncontrolled, but testing was performed to establish the magnitude of the emissions. Results indicate that emissions from taconite ore loading operations, based on annual pellet production rates, are of the order of 0.1 kilograms emitted per metric ton of pellets produced.

Windblown dust from taconite tailings can be significant due to the small size of the particles. The control currently in use is revegetation. The use of water sprays and chemical binders can reduce dusting significantly. Wind tunnel tests show that water spraying alone can reduce mass emissions from tailings by 95% under a 40 mph wind. Chemical treatment can reduce fine particle emissions (0.85 to 4.5 micron range) by 99 percent.(6-24) Current usage is not known.

Other controls of any potential radionuclide releases are secondary and are a result of particulate control. The efficiencies of particulate control devices are presented in Table 6-12, based on the emission data shown in the same table. The emission rate data are median values for 4 to 63 data points normalized with respect to the processing rate. They are therefore representative of industry wide emissions and controls.

Control efficiencies of actual devices in use at each point are presented in Table 6-13, showing both the average efficiencies and their ranges. These data are not normalized based on process rate, thus the average control efficiencies cannot be applied to the uncontrolled emission rate data given in Table 6-12 to yield controlled emission rate quantities.

From Table 6-12, it can be seen that fine crushing and waste gas together account for approximately 90% of the controlled and uncontrolled emissions from all ten sources. Seven of the ten sources each account for one percent or less of the emissions in both cases. The overall effective control efficiency for all ten sources averages 98.8%.

Employment of control devices at each point source is shown in Table 6-13. The four most commonly used controls are wet scrubbers, cyclones, baghouse collectors, and rotoclones, accounting for 49, 27, 9, and 7 percent, respectively, of control usage for those emission points surveyed. Furthermore, controls were applied mostly to waste gas streams, fine crushing, coarse crushing and ore transfer point sources. This accounted for 27, 22, 16, and 14 percent of the device totals. Each type of control device found application in from one to four source categories, with the exception of wet scrubbers which were used to control every type of source except the crude ore dump pocket.

In order to assess the relative effectiveness of these devices in controlling particulate emissions it would be necessary to know the particle size distribution of the influent and effluent for each device applied to each source. Information of this type is scarce, since particulate measurements are not routinely performed and when taken they are mostly concerned only with total particulate loading. The control efficiencies presented in Tables 6-12 and 6-13 therefore apply only to reduction of total suspended particulate emissions.

Generally, the least expensive control devices to install and operate are the dry inertial type separators, such as settling chambers, cyclones and multiclones. They are, however, severely limited in their ability to remove fine particulates and are relatively inefficient for larger particles. Wet scrubbers, baghouses, and electrostatic precipitators are more efficient devices, particularly in the small particle size range. They are more expen-

## TABLE 6-13

Control Efficiencies for Various Combinations of Control Devices and Sources* (Percent)

| Type of Control Device | Crude Ore Bump Pocket | Coarse Crushing | Ore Transfer | Fine Crushing | Bentonite Transfer | Bentonite Blending | Grate Feed | Grate Discharge | Waste Gas | Pellet Handling | Average Device Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scrubber |  | 94.6 (16)<br>91.6-99 | 99.0 (28)<br>97-99.5 | 97.7 (40)<br>97-99.6 | 98 (1) | 99.0 (2)<br>98.7-99.3 | 98.6 (8)<br>97.8-99 | 99.0 (8)<br>98-99.3 | 93.8 (2)<br>89-98.5 | 99.0 (6)<br>97.5-99.7 | 97.8 (111) |
| Cyclone | 85 (2) | 85 (1) | 95 (2) |  |  |  |  |  | 95-98 (56) |  | 95.9 (61) |
| Multiclone |  | 90 (4)<br>88-92 |  |  |  |  |  |  | 95-98 (2) |  | 92.2 (6) |
| Rotoclone |  | 91.6 (4) | 98 (1) | 99.2 (11)<br>98.3-99.7 |  |  |  |  |  | 98 (1) | 97.3 (17) |
| Bag Collector |  | 99.4 (10)<br>99-99.9 |  |  | 99 (8) | 99.2 (3)<br>99-99.7 |  |  |  |  | 99.2 (21) |
| Electrostatic Precipitator |  |  |  |  |  |  |  |  | 98.9 (3)<br>98.8-98.9 |  | 98.9 (3) |
| Dry Mechanical | 91.6 (2)<br>85-98.3 | 85 (1) | 85 (1) |  |  |  |  |  |  |  | 88.3 (4) |
| Centrifugal |  |  |  |  |  |  | 95.1 (3)<br>88-99.4 | 93.7 (2)<br>88-99.4 |  |  | 94.5 (5) |
| Average Source Control Efficiency | 88.3 (4) | 94.6 (36) | 99.7 (32) | 98.0 (51) | 98.9 (9) | 99.1 (5) | 97.8 (11) | 97.9 (10) | 96.5 (63) | 98.8 (7) | 97.1 (228) |

---

*Number in parentheses are the number of control devices surveyed for that source category. The efficiencies were based upon manufacturer's rating, field testing,or estimated, depending on data available for each individual control. Ranges of efficiencies are given below the average efficiency.

sive, however, and may be limited in use by other considerations, such as available space, temperature, inlet dust loading, etc.

Biasing the choice of devices with the desirability for efficient collection of particles in the smaller size ranges, wet scrubbers are the best control devices in general use for collection of airborne particulates for ore transfer, fine crushing, grate feed, grate discharge and pellet handling sources (bentonite handling operations will not be considered since they do not involve iron ore related materials). The results for the crude ore dump pocket are inconclusive, since the data represents only four devices and each of the two types are relatively inefficient. Control of coarse crushing emissions is accomplished mostly with scrubbers and baghouses, although baghouses appear to be better in terms of total mass emission reduction. The primary waste gas stream is controlled almost exclusively by dry inertial separators, whereas wet scrubbers and electrostatic precipitators are only in limited use.

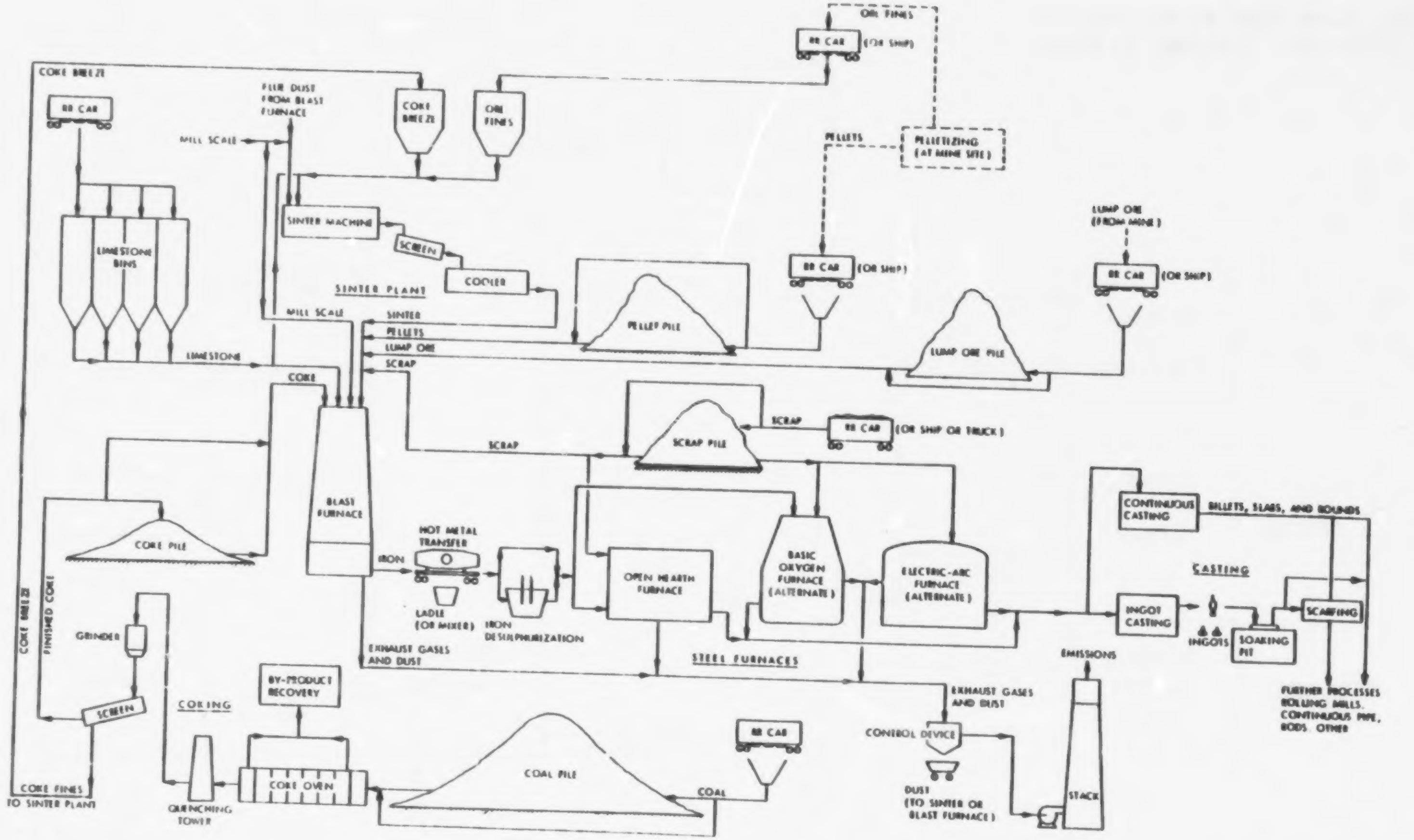
## B. Iron and Steel

### Industry Description

Once the iron ore has been processed, it is shipped by rail and/or barge to iron and steel plants. A general flow diagram of the industry is presented in Figure 6.5, which also displays the various operations from delivery of raw material to the production of finished product. The finished product is used in secondary processes such as rolling mills, pipe making, etc. The amount of materials processed by the industry in 1976 are given in Figure 6.6. The predominance of iron ore pellets as a blast furnace feed material should be noted. (6-24)

The following industry description is quoted from Desy.(6-25)

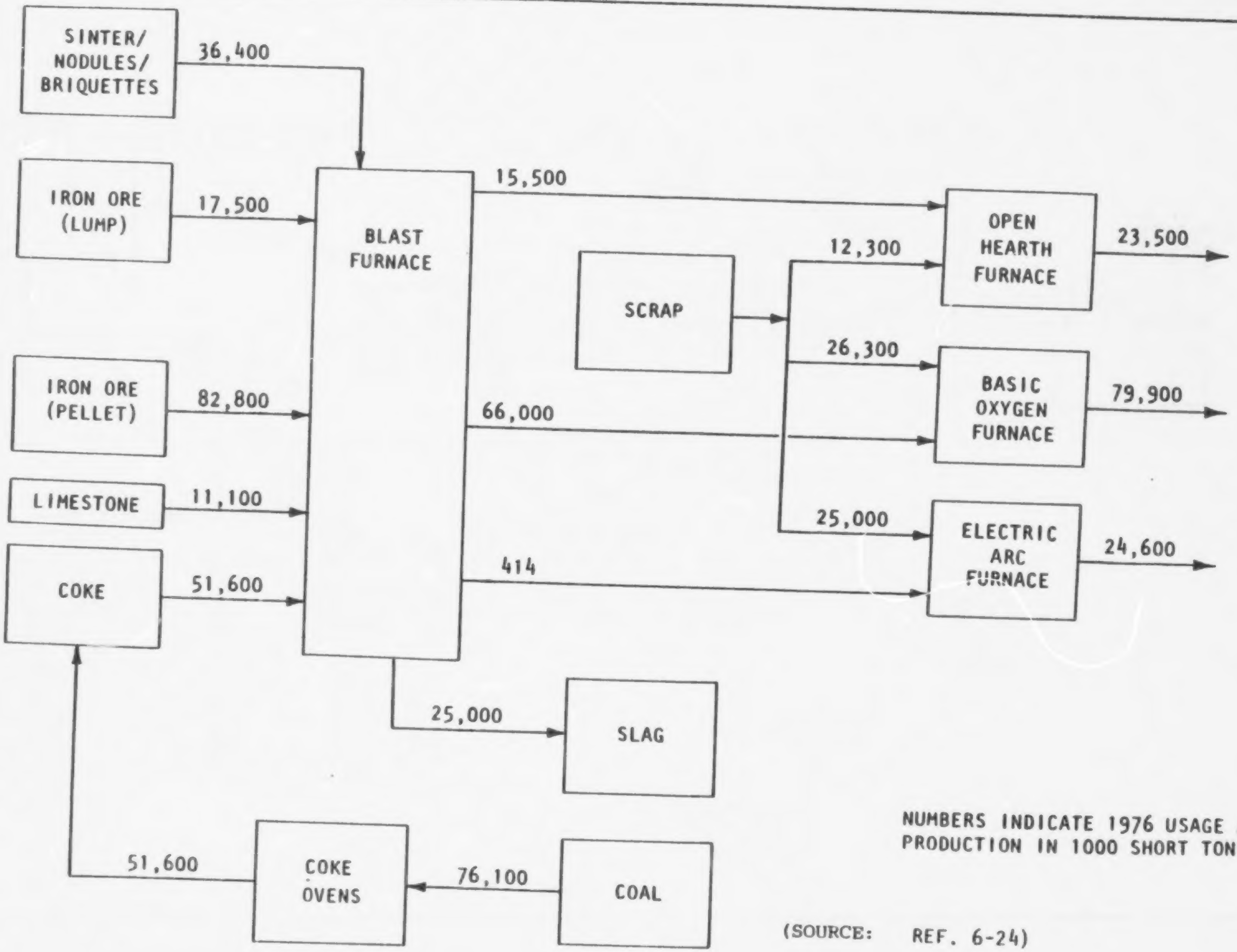
> "The steel industry of the United States is composed of approximately 180 companies which produce a wide range of steel mill products; 86 have their own steel making furnaces, and the others purchase semifinished steel for fabriction into consumer goods. In 1977, 19 companies were fully integrated, operating blast furnaces, steelmaking furnaces, and finishing mills, and 40 companies operated 51 minimills. The term minimill has been defined as an electric arc furnace steelmaking plant which produces 600,000 tons or less of raw steel annually. Pig iron was produced by 21 companies from 174 blast furnaces standing as of January 1, 1978.
>
> The steel industry produces most of its own iron ore, coal, limestone, and dolomite and operates its own coking plants, which produce a wide range of byproducts. It produces about one-fourth of the power and some of the ferralloys that it uses. Yet the steel industry buys essentially all of its fuel oil, natural gas, a large part of its fluorspar, and some metallurgical coke on the open market.


OR FINES
RR CAR (OR SHIP)
COKE BREEZE
RR CAR
FLUE DUST FROM BLAST FURNACE
MILL SCALE
COKE BREEZE
ORE FINES
PELLETS
PELLETIZING (AT MINE SITE)
LUMP ORE (FROM MINE)
LIMESTONE BINS
SINTER MACHINE
SCREEN
COOLER
RR CAR (OR SHIP)
RR CAR (OR SHIP)
SINTER PLANT
MILL SCALE
SINTER
PELLETS
LUMP ORE
SCRAP
PELLET PILE
LUMP ORE PILE
LIMESTONE
COKE
SCRAP
RR CAR (OR SHIP OR TRUCK)
SCRAP
SCRAP PILE
BLAST FURNACE
CONTINUOUS CASTING
BILLETS, SLABS, AND ROUNDS
COKE PILE
HOT METAL TRANSFER
IRON
OPEN HEARTH FURNACE
BASIC OXYGEN FURNACE (ALTERNATE)
ELECTRIC-ARC FURNACE (ALTERNATE)
CASTING
INGOT CASTING
INGOTS
SOAKING PIT
SCARFING
LADLE (OR MIXER)
IRON DESULPHURIZATION
COKE BREEZE
FINISHED COKE
GRINDER
EXHAUST GASES AND DUST
STEEL FURNACES
EMISSIONS
BY-PRODUCT RECOVERY
SCREEN
COKING
EXHAUST GASES AND DUST
FURTHER PROCESSES ROLLING MILLS, CONTINUOUS PIPE, RODS, OTHER
RR CAR
CONTROL DEVICE
COKE OVEN
COAL PILE
COAL
COKE FINES TO SINTER PLANT
QUENCHING TOWER
DUST (TO SINTER OR BLAST FURNACE)
STACK

## GENERAL FLOW DIAGRAM FOR THE IRON AND STEEL INDUSTRY

Source: Reference 6-24

FIGURE 6.5


SINTER/
NODULES/
BRIQUETTES
36,400
IRON ORE
(LUMP)
17,500
IRON ORE
(PELLET)
82,800
LIMESTONE
11,100
COKE
51,600
BLAST
FURNACE
15,500
66,000
414
25,000
SLAG
SCRAP
12,300
26,300
25,000
OPEN
HEARTH
FURNACE
23,500
BASIC
OXYGEN
FURNACE
79,900
ELECTRIC
ARC
FURNACE
24,600
COAL
76,100
COKE
OVENS
51,600

NUMBERS INDICATE 1976 USAGE AND PRODUCTION IN 1000 SHORT TONS.

(SOURCE: REF. 6-24)

1976 IRON AND STEEL INDUSTRY MATERIAL FLOWS

DAMES & MOORE

FIGURE 6.6

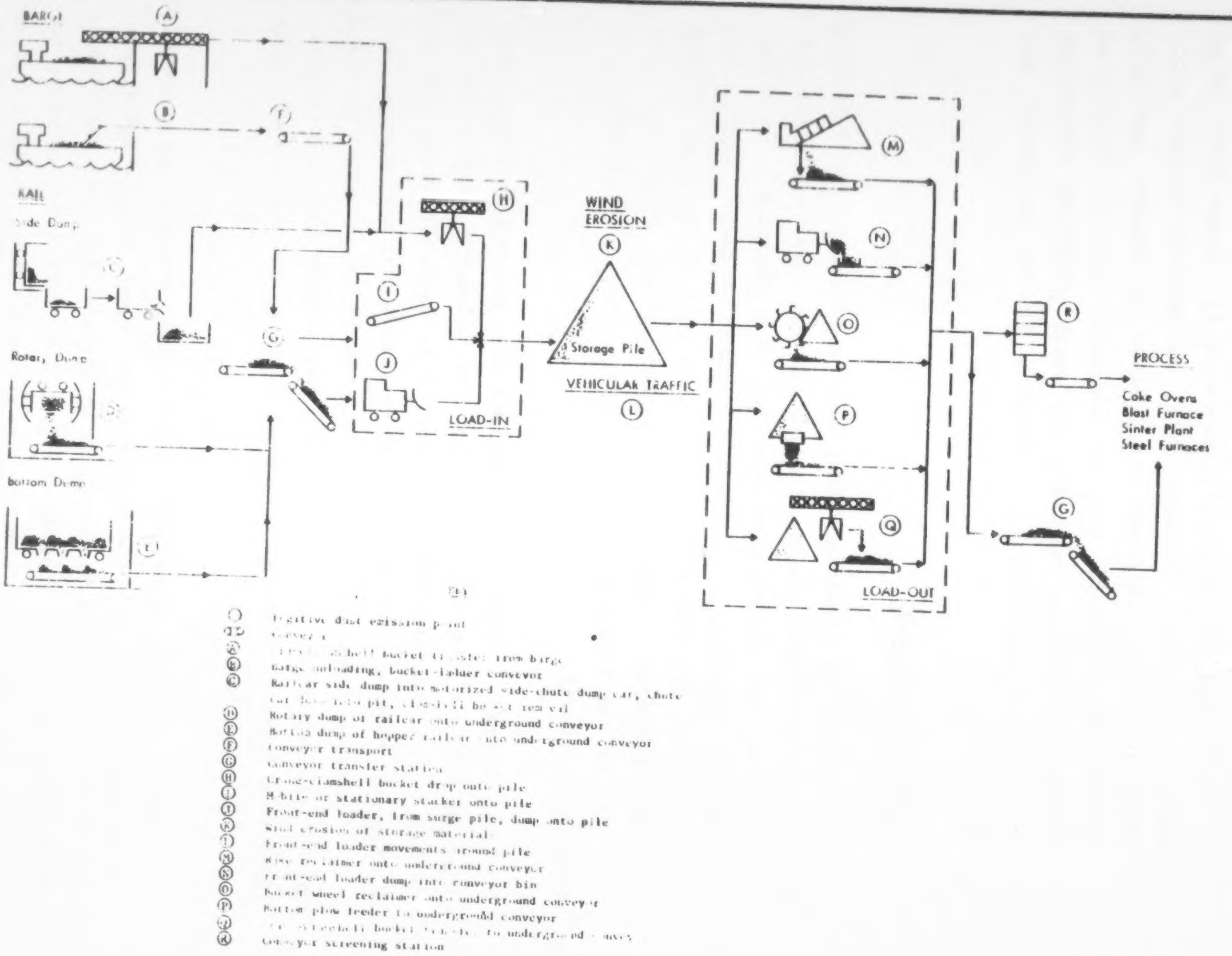
Most of the steel industry of the United States is located in the industrial complex surrounding the lower Great Lakes ports in Illinois, Indiana, Ohio, and western Pennsylvania. There are large integrated steel mills in northern New York, eastern Pennsylvania, eastern Maryland, and the Birmingham district of Alabama, and relatively small integrated steelmaking plants in west-central Illinois, Texas, Colorado, and California".

## Process Description

The processing operations that have a potential for releasing airborne radionuclides are those involving the basic raw materials, which are the iron bearing materials, coal and limestone. Steelmaking involves processing of primarily finished products, such as pig iron and scrap. For this reason, operations only to the blast furnace will be considered. Thus the processes of basic concern in this section are raw materials handling and sinter machine and blast furnace operations.

Raw material handling operations are presented graphically in Figure 6.7. They involve receipt and unloading of the raw material, which may have been transported by barge or rail, and the subsequent transfer, stockpiling, and reclamation of the material from the stockpile. The major methods employed in the material handling operations are shown in the figure. They include use of conveyors, front-end loaders, crane and clamshell buckets, and various stockpile reclaiming equipment.

The two primary operations in which raw materials are processed to produce pig iron are the sintering and blast furnace operations. The primary function of sintering is to agglomerate dusts and sludges from pollution control sources and fine ores into lumps suitable for charging into the blast furnace. The secondary function of sintering


BARGE
(A)
(B)
(F)
RAIL
Side Dump
(C)
Rotary Dump
(D)
Bottom Dump
(E)
(G)
(H)
(I)
(J)
LOAD-IN
WIND EROSION
(K)
Storage Pile
VEHICULAR TRAFFIC
(L)
(M)
(N)
(O)
(P)
(Q)
LOAD-OUT
(R)
(G)
PROCESS
Coke Ovens
Blast Furnace
Sinter Plant
Steel Furnaces
KEY
○ Fugitive dust emission point
Conveyor
(A) Crane-clamshell bucket transfer from barge
(B) Barge unloading, bucket-ladder conveyor
(C) Railcar side dump into motorized side-chute dump car, chute car dump into pit, clamshell bucket removal
(D) Rotary dump of railcar onto underground conveyor
(E) Bottom dump of hopper railcar onto underground conveyor
(F) Conveyor transport
(G) Conveyor transfer station
(H) Crane-clamshell bucket drop onto pile
(I) Mobile or stationary stacker onto pile
(J) Front-end loader, from surge pile, dump onto pile
(K) Wind erosion of storage material
(L) Front-end loader movements around pile
(M) Rake reclaimer onto underground conveyor
(N) Front-end loader dump into conveyor bin
(O) Bucket wheel reclaimer onto underground conveyor
(P) Bottom plow feeder to underground conveyor
(Q) Crane-clamshell bucket transfer to underground conveyor
(R) Conveyor screening station

IRON AND STEEL RAW MATERIAL STORAGE PILE ACTIVITIES

DAMES & MOORE

FIGURE 6.7

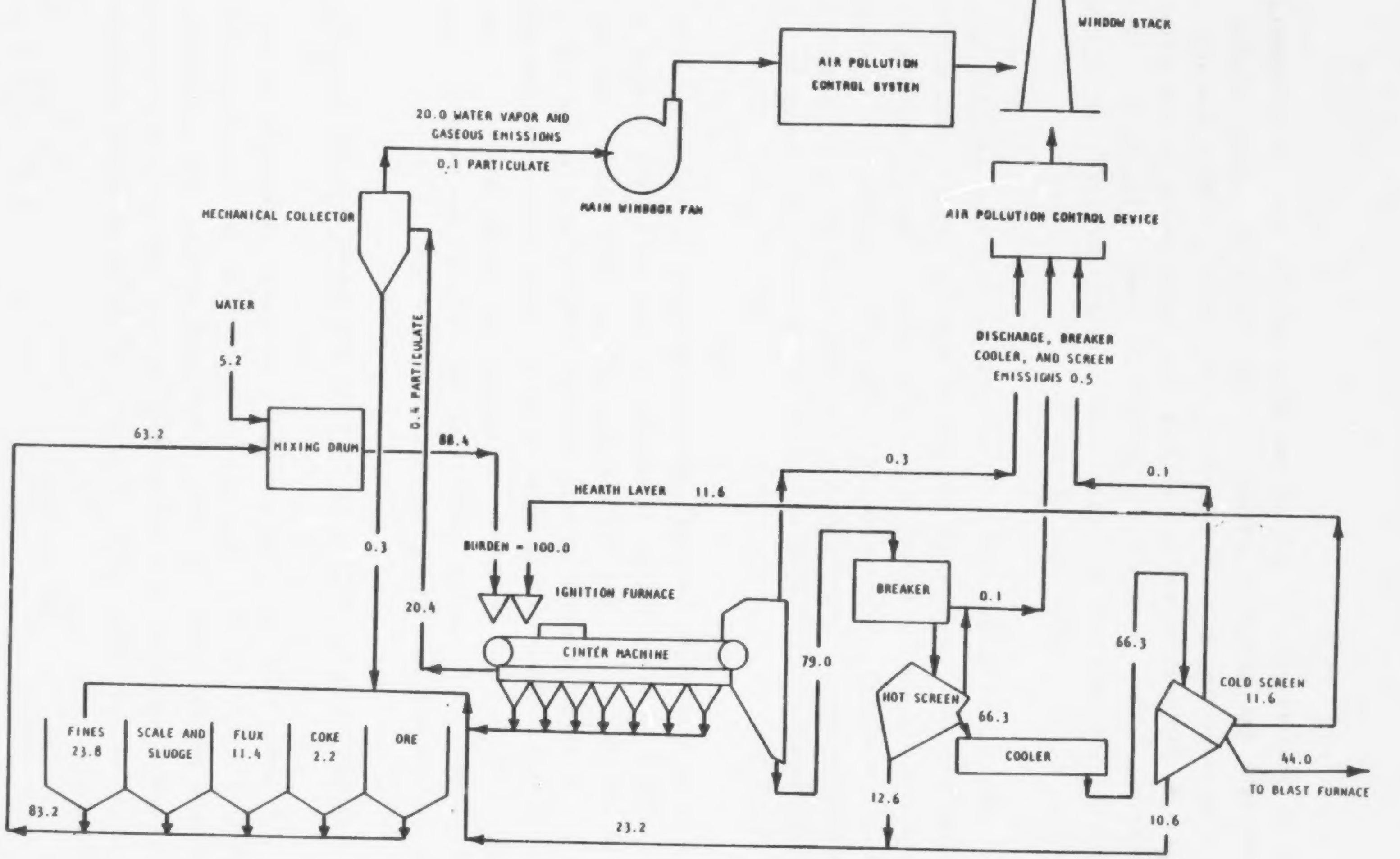
is to provide part or all of the flux material for the ironmaking process. The sintering process includes receiving, mixing, feeding, and agglomerating the raw materials; the actual sintering operation; and the crushing, screening, cooling, and transferring of the sinter product. A flow sheet for the process is shown in Figure 6.8. The numbers indicate the material flow in terms of per cent of the initial sinter machine input.(6-26)

The blast furnace converts the iron bearing feed material into molten pig iron. Wastes and impurities separate out to form a molten slag that floats on top of the liquid metal. Dust, generated by gas (primarily carbon monoxide) flowing up through the furnace burden, is removed by gas cleaning equipment. The gas is subsequently cooled to allow utilization as a fuel for various requirements of the facility.

A typical blast furnace operation is shown in Figure 6.9.(6-2) The burden (feed) material is brought to the top of the furnace by skip car and dumped into the charging system, which usually consists of two or three pressure sealing inverted cones (bells) at the top of the furnace. These are required since the blast furnace is operated under pressure, up to three atmospheres for newer furnaces. The bells operate in sequence, permitting the entry of raw material into the furnace and restricting the outward flow of gas.

## Airborne Radionuclide or Particulate Emissions and Controls

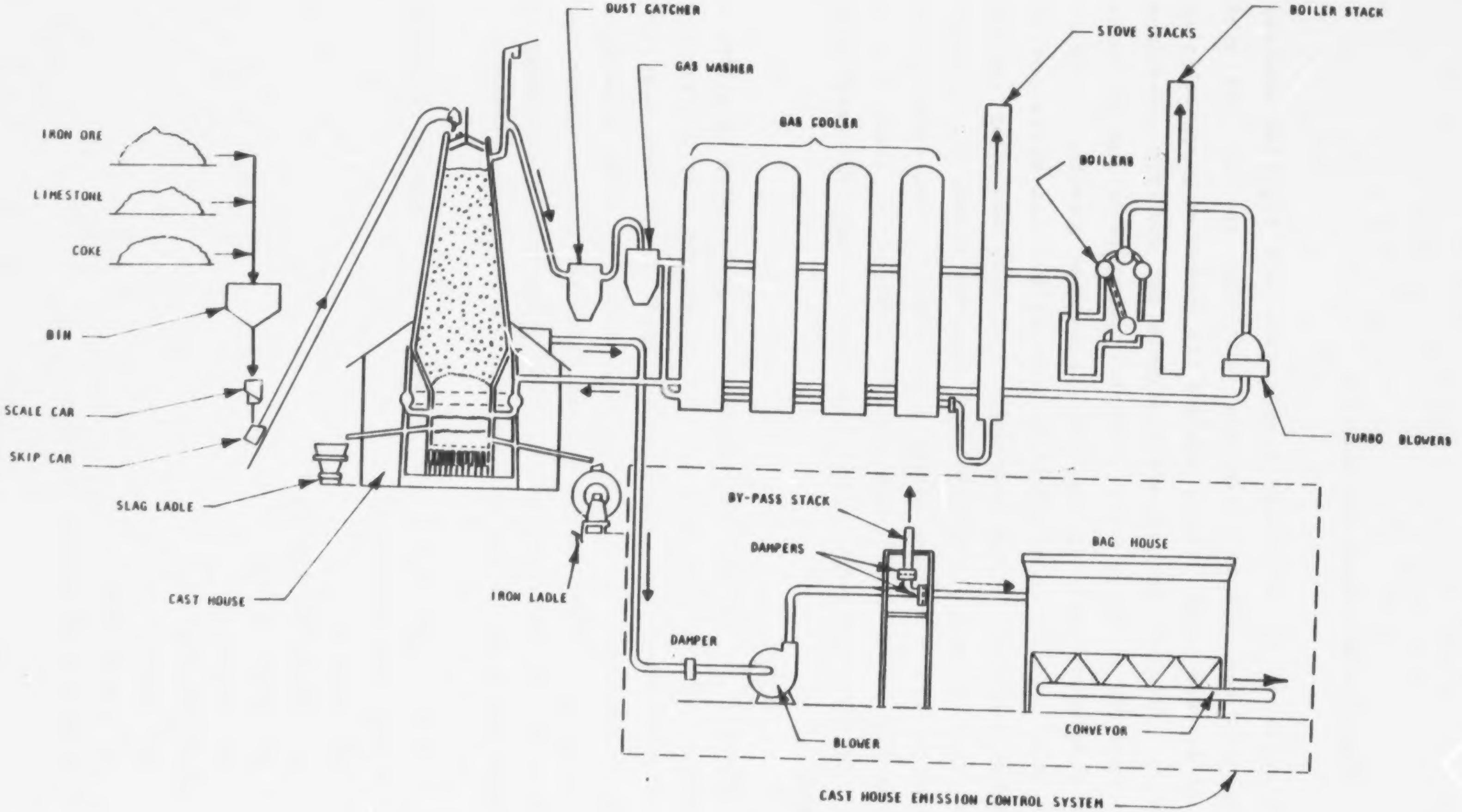
No data could be found concerning potential emmissions or controls of radionuclides possibly released from the processing of taconite pellets into pig iron. Therefore release and control of particulate emissions will be reviewed in this section. Information on each of the three major processes is presented under separate subheadings.


WINDOW STACK
AIR POLLUTION CONTROL SYSTEM
20.0 WATER VAPOR AND GASEOUS EMISSIONS
0.1 PARTICULATE
MAIN WINDBOX FAN
MECHANICAL COLLECTOR
AIR POLLUTION CONTROL DEVICE
WATER
5.2
0.4 PARTICULATE
DISCHARGE, BREAKER COOLER, AND SCREEN EMISSIONS 0.5
63.2
MIXING DRUM
88.4
0.3
0.1
HEARTH LAYER 11.6
0.3
BURDEN - 100.0
IGNITION FURNACE
20.4
BREAKER
0.1
66.3
CINTER MACHINE
79.0
HOT SCREEN
66.3
COLD SCREEN 11.6
FINES 23.8
SCALE AND SLUDGE
FLUX 11.4
COKE 2.2
ORE
COOLER
44.0
TO BLAST FURNACE
83.2
12.6
10.6
23.2

Source: Reference 6-26

ᵃPROCESS THROUGHPUTS DO NOT INCLUDE AIR.

TYPICAL SINTER PLANT FLOW DIAGRAM FOR SUPERFLUXED SINTER


IRON ORE
LIMESTONE
COKE
BIN
SCALE CAR
SKIP CAR
SLAG LADLE
CAST HOUSE
IRON LADLE
DUST CATCHER
GAS WASHER
GAS COOLER
STOVE STACKS
BOILERS
BOILER STACK
TURBO BLOWERS
BY-PASS STACK
DAMPERS
BAG HOUSE
DAMPER
BLOWER
CONVEYOR
CAST HOUSE EMISSION CONTROL SYSTEM

(SOURCE: REF. 6-27)

BLAST FURNACE PLANT WITH AUXILIARY EQUIPMENT

FIGURE 6.9

## Fugitive Emissions and Controls

The majority of particulate emissions are fugitive sources resulting from raw materials handling, vehicular traffic, and wind erosion of storage piles. These sources are presented graphically in Figure 6.7. Emission factors are available for specific operations and are presented in Table 6-14. The 1976 material production rates are also presented, yielding the total calculated quantity of uncontrolled emission for each operation for 1976. All emissions of particulates composed of raw materials, including vehicular traffic around storage piles and windblown dust from the piles, are included under storage pile activities (Table 6-14, item 3). Emissions listed under vehicular traffic and wind erosion (Table 6-14, items 4 & 5) would not be important radiologically as they are not associated with raw materials.

It can be seen from the table that the largest source of airborne particulates from raw materials are due to storage pile activities. The table also shows that approximately half of all open dust and fugitive sources are controlled by the industry. The reference document from which these data are taken discusses control technology in some detail, including optional controls which are not currently in use. These controls can be grouped into the following categories:

1) Materials handling: unloading and conveyor transfer stations
2) Storage Pile Activities
    a) load-in
    b) vehicular traffic
    c) wind erosion
    d) load-out
3) Vehicular Traffic
    a) unpaved roads
    b) paved roads
4) Wind Erosion of Exposed Areas

## TABLE 6-14A

Selection of Best Emission Factors For Open Dust Sources[e]

| Source | Units | Suspended Particulate Emission Factor Range | Best Suspended Particulate Emission Factor | Quality of Best Emission Factor Value | Percent of Suspended Particulate That Is Flue[a] | Quality of the Fine Particle Percentage Value | Best Fine Particulate Emission Factor |
|---|---|---|---|---|---|---|---|
| 1. Unloading Raw Materials | | | | | | | |
| Iron Ore | | | | | | | |
| Lump | kg/t lump ore<br>(lb/T lump ore) | -- | 0.00045<br>(0.0009) | Estimate[b] | 30 | Estimate | 0.00013<br>(0.00027) |
| Pellets | kg/t pellets<br>(lb/T pellets) | — | 0.005<br>(0.01) | Estimate | 30 | Estimate | 0.0015<br>(0.003) |
| Coal | kg/t coal<br>(lb/T coal) | 0.023-0.2<br>(0.046-0.4) | 0.023<br>(0.046) | Estimate | 35 | Estimate | 0.008<br>(0.016) |
| Limestone/ dolomite | kg/t stone<br>(lb/T stone) | -- | 0.023<br>(0.046) | Estimate | 35 | Estimate | 0.008<br>(0.016) |
| 2. Conveyer transfer stations | | | | | | | |
| Iron Ore | | | | | | | |
| Lump | kg/t lump ore<br>(lb/T lump ore) | -- | 0.00045<br>(0.0009) | Estimate | 30 | Estimate | 0.00013<br>(0.00027) |
| Pellets | kg/t pellets<br>(lb/T pellets) | -- | 0.005<br>(0.01) | Estimate | 30 | Estimate | 0.0015<br>(0.003) |
| Coal | kg/t coal<br>(lb/T coal) | — | 0.023<br>(0.046) | Estimate | 35 | Estimate | 0.008<br>(0.016) |
| Limestone/ dolomite | kg/t stone<br>(lb/T stone) | -- | 0.023<br>(0.046) | Estimate | 35 | Estimate | 0.008<br>(0.016) |
| Coke | kg/t coke<br>(lb/T coke) | 0.011-0.06<br>(0.023-0.13) | 0.023<br>(0.046) | Estimate | 35 | Estimate | 0.008 |

## TABLE 6-14A (cont'd)

### Selection of Best Emission Factors For Open Dust Sources[e]

| Source | Units | Suspended Particulate Emission Factor Range | Best Supsended Particulate Emission Factor | Quality of Best Emission Factor Value | Percent of Suspended Particulate That Is Fine[a] | Quality of the Fine Particle Percentage Value | Best Fine Particulate Emission Factor |
|---|---|---|---|---|---|---|---|
| 3. Storage pile activities | | | | | | | |
| Iron Ore | | | | | | | |
| Lump | kg/t lump ore<br>(lb/T lump ore) | -- | 0.11<br>(0.22) | Calculated[d] | 30 | Estimated | 0.033<br>(0.066) |
| Pellets | kg/t pellets<br>(lb/T pellets) | -- | 0.11<br>(0.22) | Calculated | 30 | Estimated | 0.033<br>(0.066) |
| Coal | kg/t coal<br>(lb/T coal) | -- | 0.07<br>(0.14) | Calculated | 30 | Estimated | 0.021<br>(0.042) |
| Limestone/ dolomite | kg/t stone<br>(lb/T stone) | -- | 0.06<br>(0.12) | Calculated | 30 | Estimated | 0.018<br>(0.036) |
| Coke | kg/t coke<br>(lb/T coke) | -- | 0.041<br>(0.083) | Calculated | 30 | Estimated | 0.012<br>(0.025) |
| Sinter input materials | kg/t input<br>(lb/T input) | -- | 0.18<br>(0.37) | Calculated | 30 | Estimated | 0.055<br>(0.11) |
| Slag | kg/t slag<br>(lb/T slag) | -- | 0.009<br>(0.18) | Calculated | 30 | Estimated | 0.027<br>(0.054) |
| 4. Vehicular traffic | | | | | | | |
| Unpaved roads | | | | | | | |
| Light duty | kg/vehicle-km<br>(lb/VM) | -- | 0.73<br>(2.6) | Calculated | 30 | Measured | 0.22<br>(0.78) |
| Medium duty | kg/vehicle-km<br>(lb/VM) | -- | 2.2<br>(7.8) | Calculated | 35 | Measured | 0.77<br>(2.7) |
| Heavy duty | kg/vehicle-km<br>(lb/VM) | -- | 2.8<br>(10) | Calculated | 40 | Measured | 1.1<br>(4.0) |
| Paved roads | kg/vehicle-km<br>(lb/VM) | -- | 0.27<br>(0.95) | Measured | 50 | Measured | 0.13<br>(0.47) |

TABLE 6-14A (cont'd)

Selection of Best Emission Factors For Open Dust Sources[e]

| | Source | Units | Suspended Particulate Emission Factor Range | Best Supsended Particulate Emission Factor | Quality of Best Emission Factor Value | Percent of Suspended Particulate That Is Flue[a] | Quality of the Fine Particle Percentage Value | Best Fine Particulate Emission Factor |
|---|---|---|---|---|---|---|---|---|
| 5. | Wind erosion of bare areas | $kg/km^2/yr$<br>(lb/acre/yr) | 103,000-187,000<br>(917-1,670) | 144,000<br>(1,290) | Calculated | 30 | Estimated | 43,000<br>(390) |

---

a. Weight percent of particles with a diameter less than 5 um divided by weight percent of particles with a diameter less than 30 um times 100.
b. MRI estimate based on comparison with like source.
c. Average of sampling results as reported in Table 3-7 of Reference 6-24.
d. Average calculated emission factor for the four surveyed plants (see Section 4.0 of Reference 6-24) weighted over the source extents.
e. Source: Reference 6-24.

## TABLE 6-14B

Nationwide Emissions From Open Dust Sources Based on Best Emission Factors[a]

| Source | 1976 Production Rate x $10^{-6}$ | Nationwide Emissions[b] - t/yr (T/yr) | | | | |
|---|---|---|---|---|---|---|
| | | Uncontrolled Suspended Particulate Emission Rate | Uncontrolled Fine Particulate Emission Rate | Estimated Typical Control Fraction | Controlled Suspended Particulate Emission Rate | Controlled Fine Particulate Emission Rate |
| 1. Unloading Raw Materials | | | | | | |
| Iron Ore | | | | | | |
| Lump | 15 t/yr<br>(17 T/yr) | 7.0<br>(7.7) | 2.1<br>(2.3) | 0.5 | 3.5<br>(3.9) | 1.0<br>(1.1) |
| Pellets | 79 t/yr<br>(87 T/yr) | 390<br>(430) | 120<br>(130) | 0.5 | 190<br>(210) | 59<br>(65) |
| Coal | 72 t/yr<br>(79 T/yr) | 1,600<br>(1,800) | 570<br>(630) | 0.5 | 820<br>(900) | 290<br>(310) |
| Limestone/ dolomite | 20 t/yr<br>(22 T/yr) | 460<br>(510) | 160<br>(180) | 0.5 | 230<br>(250) | 82<br>(90) |
| 2. Conveyer transfer stations | | | | | | |
| Iron Ore | | | | | | |
| Lump | 15 t/yr<br>(17 T/yr) | 7.0<br>(7.7) | 2.1<br>(2.3) | 0.5 | 3.5<br>(3.9) | 1.0<br>(1.1) |
| Pellets | 79 t/yr<br>(87 T/yr) | 390<br>(430) | 120<br>(130) | 0.5 | 190<br>(210) | 59<br>(65) |
| Coal | 72 t/yr<br>(79 T/yr) | 1,600<br>(1,800) | 570<br>(630) | 0.5 | 820<br>(900) | 290<br>(310) |
| Limestone/ dolomite | 20 t/yr)<br>(22 T/yr) | 460<br>(510) | 160<br>(180) | 0.5 | 230<br>(250) | 82<br>(90) |
| Coke | 55 t/yr<br>(61 T/yr) | 1,300<br>(1,400) | 440<br>(490) | 0.5 | 650<br>(700) | 220<br>(240) |
| Sinter | 33 t/yr<br>(36 T/yr) | 760<br>(840) | 260<br>(290) | 0.5 | 380<br>(420) | 260<br>(290) |

## TABLE 6-14B (cont'd)

### Nationwide Emissions From Open Dust Sources Based on Best Emission Factors[a]

| Source | 1976 Production Rate x $10^{-6}$ | Nationwide Emissions[b] - t/yr (T/yr) | | | | |
|---|---|---|---|---|---|---|
| | | Uncontrolled Suspended Particulate Emission Rate | Uncontrolled Fine Particulate Emission Rate | Estimated Typical Control Fraction | Controlled Suspended Particulate Emission Rate | Controlled Fine Particulate Emission Rate |
| 3. Storage pile activities | | | | | | |
| Iron Ore | | | | | | |
| Lump | 15 t/yr<br>(17 T/yr) | 1,700<br>(1,900) | 510<br>(560) | 0.4 | 1,000<br>(1,100) | 300<br>(340) |
| Pellets | 79 t/yr<br>(87 T/yr) | 8,700<br>(9,600) | 2,600<br>(2,900) | 0.4 | 5,200<br>(5,800) | 1,600<br>(1,700) |
| Coal | 72 t/yr<br>(79 T/yr) | 5,000<br>(5,500) | 1,500<br>(1,700) | 0.4 | 3,000<br>(3,300) | 900<br>(1,000) |
| Limestone/ dolomite | 20 t/yr<br>(22 T/yr) | 1,200<br>(1,300) | 360<br>(400) | 0.4 | 720<br>(780) | 220<br>(240) |
| Coke | 55 t/yr<br>(61 T/yr) | 2,300<br>(2,500) | 690<br>(760) | 0.4 | 1,400<br>(1,500) | 410<br>(460) |
| Sinter input materials | 43 t/yr<br>(48 T/yr) | 8,100<br>(8,900) | 2,400<br>(2,600) | 0.4 | 4,900<br>(5,300) | 1,400<br>(1,600) |
| Slag | 23 t/yr<br>(25 T/yr) | 2,000<br>(2,200) | 610<br>(760) | 0.4 | 1,200<br>(1,300) | 370<br>(400) |
| 4. Vehicular traffic | | | | | | |
| Unpaved roads | | | | | | |
| Light duty | 8,400,000 km/yr<br>(5,200,000 VM/yr) | 6,100<br>(6,800) | 1,800<br>(2,000) | 0.5 | 3,100<br>(3,400) | 900<br>(1,000) |
| Medium duty | 5,600,000 km/yr<br>(3,500,000 VM/yr) | 12,300<br>(14,000) | 4,300<br>(4,700) | 0.5 | 6,200<br>(7,000) | 2,200<br>(2,400) |
| Heavy duty | 8,800,000 km/yr<br>(5,500,000 VM/yr) | 25,000<br>(28,000) | 9,700<br>(11,000) | 0.5 | 13,000<br>(14,000) | 4,900<br>(5,500) |

# TABLE 6-14B (cont'd)

## Nationwide Emissions From Open Dust Sources Based on Best Emission Factors[a]

| Source | 1976 Production Rate x $10^{-6}$ | Nationwide Emissions[b] - t/yr (T/yr)<br>Uncontrolled Suspended Particulate Emission Rate | Uncontrolled Fine Particulate Emission Rate | Estimated Typical Control Fraction | Controlled Suspended Particulate Emission Rate | Controlled Fine Particulate Emission Rate |
|---|---|---|---|---|---|---|
| 4. Vehicular traffic | | | | | | |
| Paved roads | 52,000,000 km/yr<br>(32,000,000 VM/yr) | 14,000<br>(15,000) | 17,000<br>(17,500) | 0.5 | 7,000<br>(7,500) | 3,500<br>(3,800) |
| 5. Wind erosion of bare areas | 18.6 $km^2$<br>4,600 acres | 2,700<br>(3,000) | 800<br>(900) | 0.4 | 1,600<br>(1,800) | 480<br>(540) |

---

a. Source: Reference 6-24.

b. Units: t/yr = metric tonnes per year
T/yr = short tons per year

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Tables 6-15 through 6-18 present the control options for each of the above applications. Estimated efficiencies are also given, along with the installation cost and annual operating costs when available.

Sinter Machine Emissions and Controls

The major particulate emissions from the sintering process are due to the windbox exhaust system and the process equipment exhaust system (controls the discharge hood, sinter breaker, and hot screens). The principal means for controlling windbox exhausts are electrostatic precipitators (ESP), cyclones, and wet scrubbers, with the ESP being the device of choice.(6-28). The distribution and frequency of equipment employed on sinter machine windboxes at 45 plants in the U.S. is as follows:

| Control | Number | Frequency % |
|---|---|---|
| ESP's | 22 | 49 |
| Cyclones | 11 | 24 |
| Scrubbers | 9 | 20 |
| Baghouse | 1 | 2 |
| Steam Ejector | 1 | 2 |
| Mechanical | 1 | 2 |
| Total | 45 | 100% |

It should be noted that most sintering operations that use ESP control equipment also use cyclones (or mechanical collectors) as a pretreatment device.

Emission tests were performed on an ESP controlled windbox exhaust stream from a four-stranded sinter machine with an estimated production capacity of 227 metric tons per hour. The composition of the sinter mix was as follows:

## TABLE 6-15

### Materials Handling Dust Controls[f]

| Control Method | Estimated Control Efficiency (%) | Initial Cost $1977 | Initial Cost ($1978) | Annual Operating Cost $1977 | Annual Operating Cost ($1978) |
|---|---|---|---|---|---|
| Option A: Enclosures | | | | | |
| Railcar unloading station | 99[a] | 100,000 | (107,600) | NA | |
| Covering conveyor | 70 to 99[b] | 35 to 70/ft of conveyor[b] | (38 to 75) | NA | |
| Enclosing conveyor transfer station | 70 to 99[c] | 3,000 to 18,000[c] | (3,228 to 19,368) | NA | |
| Option B: Spray Systems | | | | | |
| Railcar unloading station | 80 | 30,000 | (32,280) | | |
| Conveyor transfer station | 70 to 95 | 15,000 to 200,000[d] | (16,140 to 215,200) | 0.02 to 0.04/ ton material treated[e] | (.02 to 0.4) |

---

a. Utilizes high efficiency bag filter.
b. Low value utilizes "weather tight" system; high value utilizes dust collection system.
c. Low value simple enclosure; high value enclosure plus bag filter.
d. Low value reflects control at one transfer station; high value reflects total cost for a multiple system handling $2.2 \times 10^6$ tons of material per year.
e. Wetting agent cost applies only to the $15,000 single transfer station control system.
f. Source: Reference 6-24.

N/A Not available.

## TABLE 6-16

### Storage Pile Activity Dust Controls[e]

| Control Method | Estimated Control Efficiency (%) | Initial Cost[f] ($1977) | Annual Operating Cost ($1977) |
|---|---|---|---|
| Load-in | | | |
| Option A: Reduce Drop Distance | | | |
| Stacker - height adjustable | 25 | 100,000 to 5,300,000 | NA |
| Telescopic chutes | 75 | 7,000 | NA |
| Option B: Enclosures | | | |
| Stone ladders | 80 | 20,000 | NA |
| Wind guards | 50 | 10,000 to 50,000 | NA |
| Option C: Spray Systems | | | |
| Stacker - sprays | 75 | 60,000+ | NA |
| Vehicular traffic around storage piles (see Table 6-17) | | | |
| Wind erosion from storage piles | | | |
| Option A: Surface stabilization | | | |
| Regular watering | 80[a] | 11,000 | NA |
| Surface crusting agents | up to 99[b] | 11,000+ | 0.004 to 0.1/sq. ft. |
| Option B: Enclosures | | | |
| Storage silos | 100 | 60/ton material stored | NA |
| Vegetative wind breaks | 30 | 35 to 350/tree[c] | NA |
| Low pile height | 30 | NA | NA |
| Load-out | | | |
| Option A: Reduce Material Disturbance | | | |
| Gravity-feed plow reclaimer | 85 | 35 to 60/ton material stored | NA |
| Rake reclaimer | 85 | NA | NA |
| Bucket wheel reclaimer | 80 | 2.2 to 5.3 x $10^6$[d] | NA |
| Option B: Spray Systems | | | |
| Bucket wheel reclaimer sprays | 95 | 60,000+ | NA |

---

a. Based on wind-activated sprinkler system.

b. Based on measured data, see Appendix C of reference 6-24.

c. Low value 8-ft. trees; high value 25-ft trees.

d. Based on a mobile stacker/reclaimer system.

e. Source: Reference 6-24.

f. To convert to 1978 dollars multiply by 1.076.

## TABLE 6-17

### Road Dust Controls[i]

| Control Method | Estimated Control Efficiency (%) | Initial Cost[j] ($1977) | Annual Operating Cost ($1977)[a] |
|---|---|---|---|
| Unpaved Roads | | | |
| Option A: Dust Suppressants | | | |
| Watering - regular schedule | 50 | 10,000/truck[c] | 20,000[c] |
| Road oil | 75[d] | 2,500/mile[e] | (Re-oil once a month)[c] |
| Chemicals (e.g., Coherex or Lignin) | 90 to 95 | 5,000 to 12,000/mile | 31,000 to 75,000 |
| Option B: Improvement of Road Surface | | | |
| Use of low silt aggregate | 30[d] | NA | NA |
| Oil and double chip surface | 80[d] | 9,000/mile[e] | (Resurface every 2 to 4 yr)[e] |
| Paving | 90[g] | 28,000 to 50,000/mile[e] | (Resurface every 5 yr)[c] |
| Paved Roads | | | |
| Option A: Sweeping | | | |
| Broom | 70[d] | 4,000 to 12,000/truck[h] | 15,000[d] |
| Vacuum | 75[d] | 22,000/truck[c] | 22,000[c] |
| Option B: Flushing | | | |
| Water Flushing | 80[d] | 11,000/truck[h] | 18,000[d] |

---

a. Based on a plant having 6.3 miles of upaved roadways, the average of open dust surveys of four plants.
c. Obtained from steel plant personnel.
d. Assumed by MRI.
e. Obtained from a road contractor.
g. Calculated reduction based on upaved and paved roadway emission rates.
h. Obtained from equipment manufacturer.
i. Source: Reference 6-24.
j. To convert to 1978 dollars multiply by 1.076.

N/A Not Available.

## TABLE 6-18

### Exposed Area Dust Controls[a]

| Control Method | Estimated Control Efficiency (%) | Initial Cost[d] ($/acre) | Annual Operating Cost ($/acre) |
|---|---|---|---|
| **Control Option A: Surface Stabilization** | | | |
| Watering | 50 | 600 | 4-10 |
| Chemical stabilizers | 70 | 600+ | 25-50 |
| Oiling | 80 | 85 | NA |
| Paving with cleaning | 95+ | 3,000-10,000[b] | NA |
| **Control Option B: Windbreaks** | | | |
| Windbreaks | 30 | 35-350[c] | NA |
| Vegetative ground cover | 70[a] | NA | NA |

---

a. Source: Reference 6-24.
b. Low value, oil, and double chip surface; high value, asphalt surface.
c. Low value, 8-ft high trees; high value, 25-ft high trees.
d. To convert to 1978 dollars multiply by 1.076.

N/A Not Available.

| Sinter Mix Component | Weight Percent |
|---|---|
| Iron ore | 52 |
| Reclaimed oily mill scale and flue dust | 8 |
| Reclaimed basic oxygen furnace slag | 17 |
| Limestone and dolomite | 6 |
| Coal | 7 |
| Total | 100 |

The system employed two ESP's, or two sinter-strands for each ESP. Size distribution of the particulates emitted at the outlet varied somewhat for two tests, but a rough average indicates that about half of the particles emitted, on a dry weight basis, were below five microns in size.

Use of ESP controls on sinter machine windbox exhausts is hampered by the increased use of high-basicity sinter required in modern blast furnace technology. The resultant higher limestone additions to the sinter mixture cause variations in particle resistivity and basicity that adversely affect ESP operations. In some instances, additional ESP chambers are required, with one group designed to collect the iron oxide particles and another group to collect the limestone particulates. In other instances, the ESP's were replaced by wet scrubbers to overcome the problem.

Another problem hindering ESP usage is found in iron and steel plants that are committed to the recovery of metal values from oily machine turnings. These turnings are waste material generated by facilities that produce finished steel products. The oil on the turnings enters the ESP and coats the collector plates with films of oil, making dust removal difficult if not impossible. Under these conditions, high-energy wet scrubbers are preferred and have in fact been installed on the three newest sinter plants under construction or recently placed into operation in the United States.

Exhausts from sinter machine processing equipment (sinter breaker, screens, coolers and conveyors) are controlled by mechanical collectors followed by fabric filters or low energy wet scrubbers. The fabric filter represents the best demonstrated control technology for limiting particulates from this source.(6-26) Collection efficiencies are on the order of 99%, and baghouses in current operation generally emit less than 10 $g/m^3$ of particulates. In addition to process emissions, fugitive emissions from the process are drawn into collection hoods and enclosures for subsequent removal by the filters.

Emission factors for sinter machine windboxes and process discharges are presented in Table 6-19 for both controlled and uncontrolled emissions.(6-29) They are given in terms of kilograms of particulates emitted per metric ton of pig iron produced. Control efficiencies shown simply reflect the per cent reduction in emissions as shown in the table, except for fabric filters where the efficiency is from reference 6-26. Also, it should be noted that sinter discharge emissions can be only nominally related to the pig iron production rate since process ventilation air is handled by the discharge controls. The ventilation air is used to collect fugitive emissions generated by the process and the volume of air involved depends on the process equipment configuration plus hood and exhaust system design.

### Blast Furnace Emissions and Controls

Blast furnace exhaust gases are thoroughly cleaned to eliminate as much particulate matter or possible. The major reason for cleanup is that the combustible gas is used extensively in various facility operations and must be clean to prevent deterioration of the secondary use facilities. The accepted, proven method of control is the dry cyclone followed by the wet, high energy scrubber.

The amount of dust generated and discharged with the blast furnace gas depends upon the operation of the furance and the amount

## TABLE 6-19

### Blast Furnace and Sinter Machine Emission Factors[a]

| Type of Operation | Particulate Emissions[b,c]<br>g/MT | Control Efficiency<br>% |
|---|---|---|
| A] Blast Furnace | | |
| Uncontrolled, total | 75<br>(65 to 100) | |
| Controlled | | |
| Setting chamber or dry cyclone | 30 | 60 |
| Plus wet scruber | 7.5 | 90 |
| Plus venturi or ESP | 0.75 | 99 |
| B] Sinter Machine | | |
| 1. Windbox | | |
| Uncontrolled | 10 | |
| Controlled | | |
| Dry cyclone | 1.0 | 90 |
| Plus ESP | 0.5 | 95 |
| Plus wet scrubber | 0.02 | 98 |
| 2. Discharge | | |
| Uncontrolled | 11 | |
| Controlled | | |
| Dry cyclone | 1.1 | 90 |
| Plus ESP | 0.055 | 99.5 |
| Plus fabric filter[d] | <0.11 | >99 |

---

[a] Data extracted from Reference 6-29.

[b] Emission factors expressed as grams emitted per metric ton of pig iron produced.

[c] Numbers in parenthesis indicate range of values.

[d] Emissions estimated based on efficiency, from Reference 6-26.

of preparation which has been afforded the furnace burden. Typical emissions data are presented in Table 6-19.(6-29) The associated control efficiencies are calculated based on the controlled vs. uncontrolled emissions. The controlled dust emission rate value of 750 grams emitted per metric ton of pig iron produced is higher than indicated by the range of 14 to 150 grams per metric ton given in reference 6-27. The reason for this discrepancy is not known.

Higher efficiency control devices for removal of particulates in blast furnace gas may not significantly affect overall particulate emissions from blast furnaces. Abnormal operating conditions, such as start-up and shut-down of various processes, bleeding of raw blast furnace gas to the atmosphere to prevent over-pressurization of the furnace, and back drafting (furnace gases are drawn back through the tuyeres to a hot stove where the gas is burned), result in an increase in particulate emissions occurring during normal continuous operations.(6-30) Another problem area involves the particulates emitted thorugh the furnace bell pressure seal. The bell is fitted to its seat with a tolerance of 50 microns, but 28 per cent of the particulates in raw blast furnace gas are less than 50 microns in size and thus can exit through the bell seal.(6-27) The resultant emissions, which do not enter a control device, may be on the order of 300 grams per metric ton of iron produced. Although this figure cannot be accepted as accurate due to uncertainties in the data, it indicates that significant emissions may be occurring from currently uncontrolled sources.

## The Fluorspar Industry

### Industry Description

Fluorspar is the common name of the mineral fluorite, which when purified is calcium fluoride ($CaF_2$). It is the primary commercial source of the element fluorine and hydrofluoric acid, the basis for many unique chemical compounds. The domestic fluorspar industry is relatively small. In 1977, the total quantity of ore mined was 556,000 metric tons, 88% of which was beneficiated to yield 154,000 metric tons of fluorspar shipped. This amounted to only 14% of the fluorspar consumed in the U.S. in 1977, the bulk of the demand being met by imports.(6-31)

It is estimated that the world's currently known reserves of high-grade fluorspar will be depleted by the end of the century and by-product fluorine production will substitute as a source of fluorine as fluorspar production declines. For example, there is an increasing use of fluosilicic acid, recovered from the wet-process manufacture of phosphoric acid.

Fluorspar is marketed by grade. The three principal grades, acid, metallurgical, and ceramic, are specified on the basis of $CaF_2$ content. Acid-grade fluorspar (acid spar) contains at least 97 percent $CaF_2$, metallurgical-grade fluorspar (metspar) contains between 60 and 85 percent $CaF_2$, and the ceramic-grade (ceramic spar) consists of 85 to 97 percent $CaF_2$. Ceramic spar is further classified into No. 1 ceramic (95 to 97 percent $CaF_2$), No. 2 ceramic (85 to 93 percent $CaF_2$), and an intermediate grade (93 to 95 percent $CaF_2$).(6-32)

The major use of acid spar is in the production of hydrofluoric acid, which accounted for 51 percent of domestic consumption in 1977. The acid is principally used in the aluminum industry where it is converted to aluminum fluoride.(6-32)

Metspar is used primarily as a fluxing material in ferrous smelting operations. Approximately 47 percent of the fluorspar consumed in 1977 was by the iron and steel industry.(6-32)

Ceramic spar accounted for less than 2 percent of the fluorspar output. Its principal use is in the production of certain types of glass and enamels.(6-32)

Domestic fluorspar is mined mainly in the Illinois-Kentucky district, which produced 85 percent of the nation's output in 1977. In the past, some fluorspar was mined in Arizona, Colorado, Montana, Texas and Utah but these operations have either been shut down or mined out. Those that are still producing are small operations.(6-32)

Currently, there are only four active fluorspar mining-milling operations of importance in the United States.(6-33) They are:

| | Company | Location | Mines (No.) |
|---|---|---|---|
| A) | Ozark-Mahoning Co. (Division of Pennwalt) | Rosiclaire, Ill. | Underground (3) |
| B) | Allied Chemical Corp. (Minerva Mines Division) | Cave-In-Rock, Ill. | Underground (2) |
| C) | Frontier Spar Corp. (Controlled by Marathon Oil Company) | Salem, Kentucky | Underground (1) |
| D) | Reynolds Mining Corp. (Subsidary of Reynolds Metals Company) | Eagle Pass, Texas | None |

The Ozark-Mahoning Company is the largest fluorspar producer, owning various underground mines, of which currently three are operating. Allied Chemical Corporation has two mines both of which are currently operational. The Frontier operation has been shut down for several months, but mine development work is in progress. Reynolds Mining Corporation does not operate any mines, relying solely on imports (primarily from Mexico) to supply feed for the mill. At this writing, however, Reynolds has discontinued buying Mexican ore, so it is assumed that the mill will shut down when its stockpiles are used up. Future operations will depend on demand for fluorspar. It is possible that all four of the above operations will be producing in the near future since the demand for fluorspar is increasing for the first time in several years.

In addition to mining and milling operations, there are perhaps a dozen minor fluorspar processing plants in the United States. The majority of them exist to process metspar into briquettes for use in the iron and steel industry or package dried spar for shipment to small consumers. These operations will not be considered in this report.

## Ore Geology and Radionuclide Content

The most economically important deposits of fluorspar, worldwide, occur in the following geological formations or materials:(6-32)

> Fissure veins in igneous, metamorphic, and sedimentary rocks; stratification replacement deposits in carbonate rocks; replacements in carbonate rocks along contacts with acid igneous intrusions; stockworks and fillings in shattered zones; deposits in the marginal portions of carbonatite and alkali rock complexes; residual concentration resulting from the weathering of primary deposits; recoverable gangue material in base material deposits.

The fluorspar deposits of the Illinois-Kentucky District occur as fissure veins, stratiform replacement bodies in limestone, and residual concentrates.(6-31). The two chief vein minerals are calcite and fluorspar, with sphalerite, galena, and quartz being the most common associates. Bedded replacement deposits consist mostly of fluorspar, limestone, and barite, with other associated minerals being much the same as for fissure vein deposits. Residual concentrate deposits occur when soluble calcite is removed from fissure vein deposits by downward percolating surface waters. The resultant void spaces cause the weakened veins to collapse, leaving the insoluble fluorspar mixed with residual clay and broken up wall rock.(6-34)

Fluorspar deposits cannot in general be associated with enhanced concentrations of natural radioactivity. What relationships have been reported (6-35), have been based mostly on elevated radon daughter working level (WL) concentrations in underground mines or associated uranium. For example, the Spore Ridge fluorspar deposits, about 80 miles northwest of Delta, Utah, contain about 0.20% $U_3O_8$. Through the years the production from the several small mines has gone to Geneva Steel Company at Provo, Utah for use as metspar. It is a high-grade (90% $CaF_2$) soft, powdery ore that requires no beneficiation. However, the mines appear to be more or less depleted, and no new deposits have been found.(6-33)

Similarly, during World War II a fluorspar deposit in the Jamestown Mining District (about 25 miles northwest of Boulder, Colorado) was surveyed for radioactive ore. There were no major findings. However, at a depth of about 1200 ft, many years later, the radioactivity of the mine water discharging from the Burlington Mine became elevated. This may have been a factor in Allied Chemical closing down the mine in 1974, although the main reason was that the small mine and mill were not economical.(6-33)

The fluorspar industry is also highly concentrated in the Illinois-Kentucky District where fluorspar deposits do not exhibit association with enhanced radioactivity. Furthermore, fluorspar mined in the western states is typically sold after only minor preparation with no drying operations involved. The major source of particulate emissions in western fluorspar operations, therefore, is mining. However, western fluorspar mining represents a minor segment of the total industry and generally involves underground mining methods.(6-33)

In summary, levels of natural radionuclides associated with particulate emissions from the fluorspar industry are not known, but should be at or near background levels for the major portion of the industry. Potentially enhanced radionuclide emissions from western operations are associated with very minor operations that currently process the ore to only a limited degree.

## Process Description*

The domestic fluorspar industry employs ore concentration and beneficiation methods to process mined and imported ore for the production of an upgraded product that can be marketed. A flow sheet showing the major steps involved is shown in Figure 6.10. It is representative of the four major fluorspar producing companies listed previously. Specific operating data for the four companies are presented in Table 6-20. The data include production estimates for 1977, which include grade of ore processed and sizes of storage piles and tailings ponds.

Practically all domestic fluorspar ore is produced from underground mines. The ore is hoisted to the surface and either stockpiled for later use or fed directly into the primary crusher bin. Imported ore is stockpiled and reclaimed for feeding into the crushing circuit. Ore crushing is performed in several stages to produce a properly sized (screened) feed material (for the pre-concentration operation) usually between 1/8 inch and 2 inches. Undersized material is sent directly to the mill for benefication.

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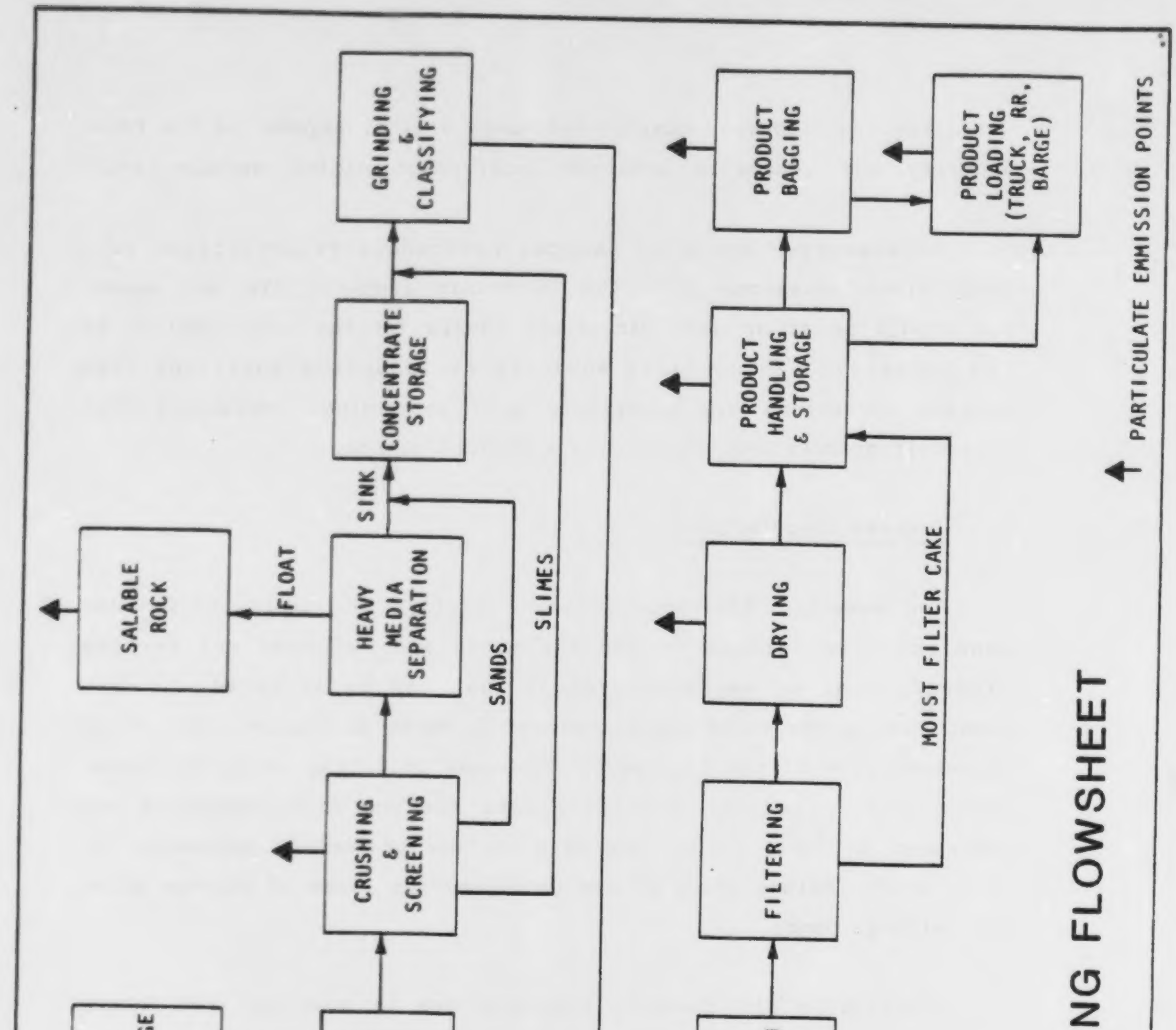
*(The remainder of this section is based primarily on unpublished information from References 6-33, 6-36, 6-37).


UNLOADING IMPORTED ORE
ORE STORAGE
MINING & HOISTING
CRUSHER BIN
CRUSHING & SCREENING
HEAVY MEDIA SEPARATION
SALABLE ROCK
FLOAT
SINK
SANDS
SLIMES
CONCENTRATE STORAGE
GRINDING & CLASSIFYING
TAILINGS POND
FROTH FLOATATION
FILTERING
MOIST FILTER CAKE
DRYING
PRODUCT HANDLING & STORAGE
PRODUCT BAGGING
PRODUCT LOADING (TRUCK, RR, BARGE)
PARTICULATE EMMISSION POINTS
DAMES & MOORE

FLUORSPAR PROCESSING FLOWSHEET

FIGURE 6.10

## TABLE 6-20

### Operating Data - Major Mines and Mills[a]

| Mill | Mines | Crude Ore Processed MT/y | Ore Grade (CaF2) % | Ore Storage Area Acres | Production Estimates: HMS Concentrate MT/y | Production Estimates: Final Product[b] MT/y | Production Estimates: Flotation Tailings MT/y | Tailings Ponds: Active Acres | Tailings Ponds: Inactive Acres |
|---|---|---|---|---|---|---|---|---|---|
| A | Underground | 240,000 | 25-45 | 3 | 145,000 | 63,000<br>(190) | 82,000 | 30 | 25 |
| B | Underground | 218,000 | 30-45 | 2 | 109,000 | 42,000<br>(150-200) | 67,000 | 6 | 31 |
| C | Underground | 41,000 | 35-40 | 0.5 | 27,000 | 14,000<br>(100) | 14,000 | c | 3 |
| D | None[e] | 118,000 | Various | d | None[e] | 64,000<br>(160-230) | 54,000 | 47[f] | --- |
| Total | --- | 617,000 | --- | | 281,000 | 183,000[g] | 217,000 | 77 | 59 |

---

[a] Estimates obtained from Reference 6-31. Production rates are given in metric tons per year, estimated for 1977.

[b] Numbers in parentheses indicate the approximate fluorspar dryer capacities (or range if varying) in metric tons per day of dry fluorspar concentrates produced. Some fluorspar is sold without drying.

[c] Plant not currently operating, but will resume production in near future.

[d] Not known. General mill site is 50 acres, which includes ore storage, mill, and other buildings.

[e] No mines are operated. All ore is imported, primarily from Mexico. Ore is fed directly into mill and is not pre-concentrated in an HMS plant.

[f] Includes 2 ponds in parallel, 20 acres and 27 acres. Does not include 155 acre overflow evaporation pond.

[g] Due to difficulty involved in estimating production breakdown by company without having actual company figures, this total does not equal the estimate of 154,000 MT given by the Bureau of Mines, but is more indicative of mill capacities during a year of normal demand for fluorspar.

Ore pre-concentration is accomplished by heavy-media separation (HMS), which relies on the difference in specific gravities for separation of the fluorspar minerals from the gangue material. The HMS plants process the crushed ore (20 to 40 percent $CaF_2$) to yield a concentrated product (40-60 percent $CaF_2$) for feeding into the flotation circuit. These HMS plants are generally located at or near the mines to minimize the costs associated with haulage of unwanted waste rock or gangue material. Wastes from the HMS plant are conveyed to ground storage, and occasionally marketed as roadrock between 1/8 inch and 2 inches in diameter.

Heavy media concentrate is generally conveyed to ground storage for drainage. When the mill is located remote from the HMS plant (several miles), undersized material (slimes) are thickened, filtered, and blended with the concentrate, then hauled to the mill. When the HMS plant and mill are located in one place, the thickened slimes are pumped directly to the mill grinding circuit. Generally, the HMS plant is operated 16 hours per day, five days per week, to produce feed for a continuously operating mill.

The mill employs wet grinding circuits to reduce the ore concentrate to 65-85 percent minus 200 mesh, the usual size required for flotation feed. Since fluorspar generally occurs with other minerals, multiple flotation circuits may be employed in series for recovery of up to four products. The usual order of flotation is galena, sphalerite, fluorspar, and finally barite. The rejected gangue material is sent to the tailings pond for disposal.

Fluorspar flotation concentrates are filtered to remove moisture, then dried in rotary kilns. The dried product is then stored in silos to await shipping, which is done either in bulk or after bagging in 100 pound bags. Shipping may be by truck, rail, or barge, and some of the product may be shipped as moist filter cake without drying.

## Airborne Radionuclide or Particulate Emissions

No data could be found to assess the release of natural radionuclides into the air from any of the various fluorspar operations. This section, therefore, examines airborne particulate releases and assumes that radionuclides in emitted particles may be qualitatively correlated.

Emissions of radon gas are not addressed since data are nonexistent and no non-radioactive gaseous emissions are measured or controlled that would allow assessment of radon control.

Emissions of airborne particulate matter from fluorspar mining and processing are limited due to the nature of the operations involved. Fluorspar mines in the major mining district in Illinois and Kentucky are all underground. These mines are characteristically wet, and additional water is frequently used to help move the ore in chutes. Underground haulageways and work faces are wet and hence do not present a dust problem. Also, overburden and waste rock are not produced from underground mines, thus eliminating a potential particulate emissions source.

Ore is crushed at the preconcentration (HMS) plant, which usually is located at the mine site. Crushers are generally located outside or in well ventilated buildings. No controls are used to limit this emission source, but the degree of emissions are small due to the moist nature of the ore.

Fugitive dust emissions from haulage roads are negligible since the HMS plants are located at or near the mine site. Emissions that do occur are not important, since they are not associated with the ore, as might be the case in open pit mines. Fugitive emissions from ore storage piles are also negligible, since the ore is wet and the ore storage piles are small (Table 6-20). No controls are employed to limit fugitive emissions from these sources.

Ore is transferred to the crusher bin either directly from the mine by hoisting skips, or by conveyor or front end loader from the storage pile. Subsequent transfer within the crushing stages and from the crushing circuit to the HMS plant is by conveyor. The ore is still moist during this phase of the operation, hence particulate emissions are minor. Controls are generally not employed, except at one plant that uses a water spray. Also, the number of external transfer points generally are minimal (2 to 6).

The ore enters the heavy media separation circuit from the crushing stage. From this point the operation is a wet process and hence does not produce airborne particulates. The heavy media concentrate is fed into the froth flotation plant directly, or stored temporarily to allow drainage of excess liquids. Waste material from the HMS plant consist of pebbles in the 1/8 inch to 2 inch size range. Waste from the flotation circuit, which incorporates wet grinding equipment for size reduction, is disposed to tailings ponds. The size of the tailings ponds are relatively small (Table 6-20). The active ponds are generally wet and do not contribute to fugitive emissions. The inactive ponds are also small, totaling about 70 acres for all three major producers of domestic ore. Control techniques are not generally employed to limit fugitive emissions from inactive piles, as they are mainly located in remote areas, and rainfall contributes enough moisture to limit dusting to a minor level. Furthermore, vegetation tends to cover abandoned tailings ponds in a few years.

Fluorspar filter cake from the froth flotation circuit is dried in a rotary kiln at temperatures up to 600 degrees fahrenheit. This burns off the fatty acid from the flotation froth which tends to coat the fluorspar particles and render them objectionable to hydrofluoric acid plants. Dryer operations can vary greatly from mill to mill, in terms of loading, draft, temperature, lifters, and other variables. Dryers are of two main types, counter-flow and parallel-flow (based on the direction of air and solids flow within the dryer). The parallel-flow dryer generates more dust than the counter-flow type. Both employ lifters to shower the load into the air stream, hence the mass of airborne particulates generated is very large, ranging from six to eighteen per cent of the dryer feed material. These emissions are well controlled with two or three stages of control devices. The recovered material is all marketable, and amounts recovered are of value. Particulate emission parameters for dryer operations are presented in Table 6-21 for five separate fluorspar dryer exhaust streams. Mill A has duplicate dryer systems, Mill B has two different systems, and Mill D combines the exhausts from two dryers, after separate pre-cleaning, into one terminal control device. Basic control types, efficiencies, and effluent quantities are also presented in the table.

After the product is dried, it is discharged to a screw conveyor for transport to an elevator. The elevator discharges the product to a storage bin after a screening step. The product handling facilities are more or less dust tight, and dusting is minimal. One estimate of the combined emission from these sources yields a total particulate release of approximately 0.2 kilograms per metric ton of product handled, with about ten per cent (0.02 kg/MT) of the mass in the respirable size range.(6-35) Based on this estimate, the total particulate emissions from these sources are about one-half of the emissions from the average controlled fluorspar dryer stacks. The respirable emissions would be only about five percent of dryer emissions, assuming all particles emitted by the dryer are in the respirable range. Bagging and bulk loading in trucks are a significant source of dust and spillage although of short duration. Three of the mills (A, C and D) do practically no bagging, while the fourth (B) might average bagging 65 tons per day, covering a bagging period of 2 or 3 hours. Two of the mills (A and D) are on railroad sidings and load direct from production to hopper cars, with practically no dusting. One mill (B) loads trucks from bins and unloads into covered

## TABLE 6-21

### Particulate Emissions and Controls - Fluorspar Dryers

| Particulate Control Parameters | Fluorspar Dryers - By Mill | | | | |
|---|---|---|---|---|---|
| | A | B | | C | D |
| | | #1 | #2 | | |
| I. Concentrate Dryers | | | | | |
| a. Number Used | 2 | 1 | 1 | 1 | 2 |
| b. Air Flow | Counter | Counter | Parallel | Counter | Counter |
| c. Effluent Temp. (°F) | 800[a] | 300 | 350 | N/A | 350 |
| d. Concentrate Production - (Mt/day) | 190-210 | 65 | 90-130 | 70 | 160-230 |
| II. Uncontrolled Emissions (kg/Mt)[b] | 140 | 80 | 150 | 100 | 100 |
| III. Emission Controls | | | | | |
| a. Primary Type | Cyclone (2)[h] | Cyclone | Cyclone | Cyclone | Cyclone |
| 1. Effluent (kg/Mt) | 35 | 20 | — | 25 | — |
| 2. Efficiency (%)[c] | 75 | 75 | — | 75 | — |
| b. Secondary Type | — | — | Cyclone | — | Cyclone |
| 1. Effluent (kg/Mt) | — | — | 25 | — | 12 |
| 2. Efficiency (%) | — | — | 83.3[d] | — | 88[d] |
| c. Secondary or Tertiary | Fabric Filter (2)[h] | Wet Scrubber | Fabric Filter | Fabric Filter | Electrostatic Precipitator |
| 1. Effluent (kg/Mt)[e] | 0.07 | 1.0 | 0.05 | 0.10 | 0.60 |
| 2. Efficiency (%) | 99.8[f] | 95[c] | 99.8[f] | 99.6[f] | 95[f] |
| IV. Overall Control Eff. (%)[g] | 99.95 | 98.75 | 99.75 | 99.9 | 99.4 |

---

[a] Highest temperature dryers in use. Cyclone exhausts are cooled with outside air in a heat exchanger.

[b] Finely divided fluorspar concentrate, 88-97% $CaF_2$, 50-60% minus 325 mesh (45 microns).

[c] Efficiencies estimated from emission data. Essentially equal to the theoretical efficiency for that particle size range.

[d] Efficiency is combined for the first two stages of control. Calculated based on influent vs. teritary

hopper cars some 22 miles distant. There are no controls at any of these dust sources, but there is careful monitoring and equipment maintenance to reduce the loss of a valuable product. Lack of data limits any accurate estimate of these dust losses.

## Airborne Radionuclide or Particulate Emission Controls

Controls are not employed in the fluorspar industry to specifically limit radionuclide emissions. Therefore, particulate emission controls will be reviewed.

The fluorspar dryers are the only emission sources where substantial material losses can occur. The emissions are controlled, and the relevant control data are presented in Table 6-21. The only devices considered are the terminal control devices*, since one or two stages of cyclone type pre-cleaners are standard. It can be seen from the data that the best terminal control devices in current use are fabric filter systems, if collection efficiency is the only criteria considered. Other important conditions must be considered, however. For example, although wet scrubbers appear to be somewhat less efficient than fabric filters, Mill B uses one on its No. 1 (counter flow) dryer. The dust generated by that dryer is more "wetable" than from other dryers. The scrubber employed is somewhat oversized, therefore good results are obtained for that system. The electrostatic precipitator employed at Mill D is also less efficient than the fabric filters, but the reason may be that it is said to be somewhat undersized for the two exhaust streams that it handles and, hence, is overloaded. In general, trial and error has played a part in the selection of the current controls. One mill employed scrubbers and a filter with unsatisfactory results. These were finally replaced with a different type of fabric filter with improved bag wear characteristics. Another mill tried two different wet scrubbers, then another scrubber in series with the first, and finally replaced them all with a fabric filter.

---

* Terminal control device refers to the final high efficiency (relative to the pre-cleaners) cleaning device employed on the waste gas stream immediately prior to atmospheric release (e.g., fabric filter system).

Cost parameters for the terminal control devices are presented in Table 6-22. The data is based on information from unpublished sources. Much of it is estimation. Labor costs are especially difficult to specify since control equipment operation and maintenance labor is often part of the normal duties of the dryer operator and therefore no record is kept separately.(6-31).

There is insufficient data to accurately assess the economics of the control devices. There are only five devices in operation, and only one of those has been in operation for more than ten years. The three fabric filter systems were installed only about four years ago, and one of those is a shop-built device of relatively high cost. The annual cost of the devices are reasonably similar, however, and are in the range of about 14 to 28 dollars per metric ton of dried fluorspar product collected by the device.

Residual material recovered from the control devices is high grade fluorspar (acid spar or metspar) and is marketable. The overall effect of operating the control devices is therefore positive in an economic sense, resulting in approximately seven times as much income from the sale of product recovered from the terminal device as is spent on operating and monitoring the device. The return is even greater if the total air cleaning system is considered.

## TABLE 6-22

### Fluorspar Dryers - Costs for Terminal Control Devices

| Control Device Information | Fluorspar Dryers - By Mill | | | | |
|---|---|---|---|---|---|
| | A | B #1 | B #2 | Ca | D |
| I. Terminal Control Device | Fabric Filter (2) | Wet Scrubber | Fabric Filter | Fabric Filter | Electrostatic Precipitator |
| II. Manufacturer | Built in Plant Shop | American Air Filter | Flex-Kleen[f] | Klex-Kleen[f] | Pollution Control, Inc. |
| III. Type | --- | W-Rotoclone | Pulse-Jet | Pulse-Jet | Unavailable |
| IV. Installation Date | 1975/76 | 1950 | 1974 | 1975 | 1968 |
| V. Device Lifetime (y) - theoretical | 20 | Unavailable | 15 | 15. | 10 |
| VI. Replacement Parts | | | | | |
| A. Description | Bags | Impeller | Bags | Bags | --- |
| B. Material | NOMEX | Stainless Steel | NOMEX | NOMEX | --- |
| C. Number per device | 480 | 1 | 144 | 128 | --- |
| D. Lifetime (months) - actual | 24 | 3-36 | 18 | 12 | --- |
| E. Unit cost ($) | 10 | 900 | 10 | 10 | --- |
| VII Costs | | | | | |
| A. Installation[b] | | | | | |
| 1. Material ($) | <200,000 (242,200) | 15,000 (40,650) | 18,000 | 20,000 | Unavailable |
| 2. Labor - a) ($)[c] | Included | Included | 10,000 | 15,000 | Unavailable |
| b) person-hrs | --- | --- | 1,670 | 1,250 | --- |
| 3. Total ($) | <200,000 (242,200) | 15,000 (40,650) | 28,000 (24,796) | 35,000 | Unavailable |
| B. Annual Cost | | | | | |
| 1. Material ($) | 6,800 | 1,500 | 1,500 | 1,500 | 1,000 |
| 2. Labor - a) ($) | 4,000 | 1,000 | 1,500 | 1,500 | 2,000 |
| b) person-hrs | 670 | 167 | 250 | 250 | 333 |

## TABLE 6-22 (cont'd)

| Control Device Information | Fluorspar Dryers - By Mill | | | | |
|---|---|---|---|---|---|
| | A | B | | C[a] | D |
| | | #1 | #2 | | |
| 3. Energy a) hp[d] | 100 | 15 | 19 | 15 | 30 |
| b) $/hp-day | 0.56 | 0.56 | 0.56 | 0.48 | 0.72 |
| c) Operating days/y | 330 | 160 | 200 | 150 | 300 |
| d) Energy Cost ($) | 18,500 | 1,350 | 2,125 | 1,080 | 6,500 |
| 4. Water ($) | --- | 200 | --- | --- | --- |
| 5. Total Annual Cost ($) | 29,300 | 4,050 | 5,125 | 4,080 | 9,500 |
| C. Relative Cost ($/MT of product collected)[e] | 14.36 | 18.41 | 28.47 | 13.60 | 15.08 |
| VIII. Solid Residuals | | | | | |
| (MT/y dry fluorspar collected) | | | | | |
| A. Cyclones | 6,110 | 640 | 2,060 | 820 | 4,800 |
| B. Terminal Control | 2,040 | 220 | 180 | 300 | 630 |
| C. Total (excluding losses) | 8,150 | 840 | 2,240 | 1,120 | 5,430 |

---

[a] Never operated consistently. Costs based on assumption of 150 days of operation per year.

[b] Installation costs in dollar-value for year of installation.

[c] Based on 1979 wage scale of $6/hr. Actual maintenance and operating requirements may be incorporated into normal duties lot dryer operator and hence would be difficult to specify accurately.

[d] Includes use of electricity, converted into horsepower. The terminal device uses approximately one-half of the energy consumed by the total control system.

[e] Relative cost is the operating cost of the terminal device per metric ton of product collected by the device. Current value of collected product is about 140 per metric ton, thus profits are realized by using controls.

[f] Flex-Kleen division of Research-Cottrell.

## The Phosphate Industry

### Industry Description

Phosphorous is an essential nutrient in agriculture, for which there are no substitutes. Phosphate rock is currently the only source of phosphorous, and no methods of recycling or recovering from secondary sources exist. Fertilizer accounts for approximately 80 percent of U.S. demand for phosphate rock. The remaining 20 percent is used for animal feed and other food products, detergent, and non-food related chemical industries.(6-38)

The mining of phosphate rock is the fifth largest mining industry in the United States, in terms of quantity of material mined.(6-39) The U.S. production of phosphate rock totalled 47.2 million metric tons in 1977 and was estimated to reach 49.3 million metric tons in 1978.(6-40) This is approximately 40 percent of the total world production of phosphate rock. The United States presently exports roughly 25% of the quantity it produces, and accounts for about 30 percent of the worldwide demand for phosphate rock.

The domestic phosphate rock industry is concentrated in three major areas, the Southeastern Region (Florida and North Carolina), the Western States Region (Idaho, Montana, Utah, and Wyoming), and Tennessee. The estimated 1978 production quantities from these regions were 42.2, 5.3, and 1.8 million metric tons, respectively.(6-40)

Production of phosphate rock has increased steadily in the past 30 years, increasing an average of about 6% per year.(6-41) This trend will probably continue into the foreseeable future, but the growth rate will decrease to approximately 2.2 percent annual average through the year 2000. Within this time period, production from Tennessee is expected to terminate (1990) and Western States production will probably increase slowly to greater than 7 million metric tons. In the Southeastern Region, production from Florida will probably peak in the mid-1980's at about 43 million metric tons and decline after 1990. North Carolina should show a strong increase from about 3 million metric tons in 1978 to an estimated maximum possible mining rate of 20 million metric tons by the year 2000.(6-38)

During the 1970's, 15 companies produced over 95% of the phosphate rock mined in the U.S. Nine of these companies produced 81% of the 1977 total from the Florida mines alone. Due to the capital-intensive nature of the industry, these companies are expected to continue as the predominant phosphate rock producers through the end of the century. A list of the principal producers in central Florida is presented in Table 6-23. Individual plant capacities are also shown, and the total plant capacity is compared to the total U.S. capacity. (6-42)

A flowsheet of the phosphate rock industry is presented in Figure 6.11, showing the supply-demand relationships for the industry. The data are for the year 1975, the most recent year where complete data were readily available. In that year, industry stocks were increased, thus yielding a negative contribution to the supply. Stocks normally vary and thus can represent either supply or demand in any one year.

Almost all phosphate rock consumed in the U.S. is initially processed to either phosphoric acid or elemental phosphorus. Phosphoric acid is produced in "wet-process" phosphoric acid plants, whereas elemental phosphorus is produced in "dry-process" electric furnace plants. The major portion of phosphate rock production from the Southeastern Region and much of the Western States Region production are consumed in wet-process plants. Most of the remaining production from the Western States Region and all of Tennessee's are treated by the dry-process.

## TABLE 6-23

## Central Florida Phosphate Rock Producers[a]

| Company | County | City | 1978 Plant Capacity[b] |
|---|---|---|---|
| Agrico Chem-Williams | Polk | Pierce | 5,400 |
| | Hardee | Fort Green | 3,200 |
| Borden Chemical | Polk | Tenoroc | 900 |
| Brewster Phosphates | Polk | Brewster | 5,700 |
| Gardinier | Polk | Ft. Meade | 1,800 |
| W.R. Grace | Polk | Bonny Lake | 2,300 |
| | Polk | Hooker's Prairie | 2,500 |
| International Minerals | Polk | Bonnie | 2,700 |
| | Polk | Kingsford | 8,600 |
| Mobil Chemical Co. | Polk | Nichols | 1,400 |
| | Polk | Ft. Meade | 2,900 |
| Poseidon Mines | Polk | Lakeland | 540 |
| Swift Chemical | Polk | Bartow | 2,700 |
| T-A Minerals Corp. | Polk | Polk City | 450 |
| USS Agri-Chem | Polk | Ft. Meade | 1,800 |
| Central Florida Total | | | 43,000 |
| United States Total | | | 60,500 |
| Central Florida - % of U.S. Total | | | 71 |

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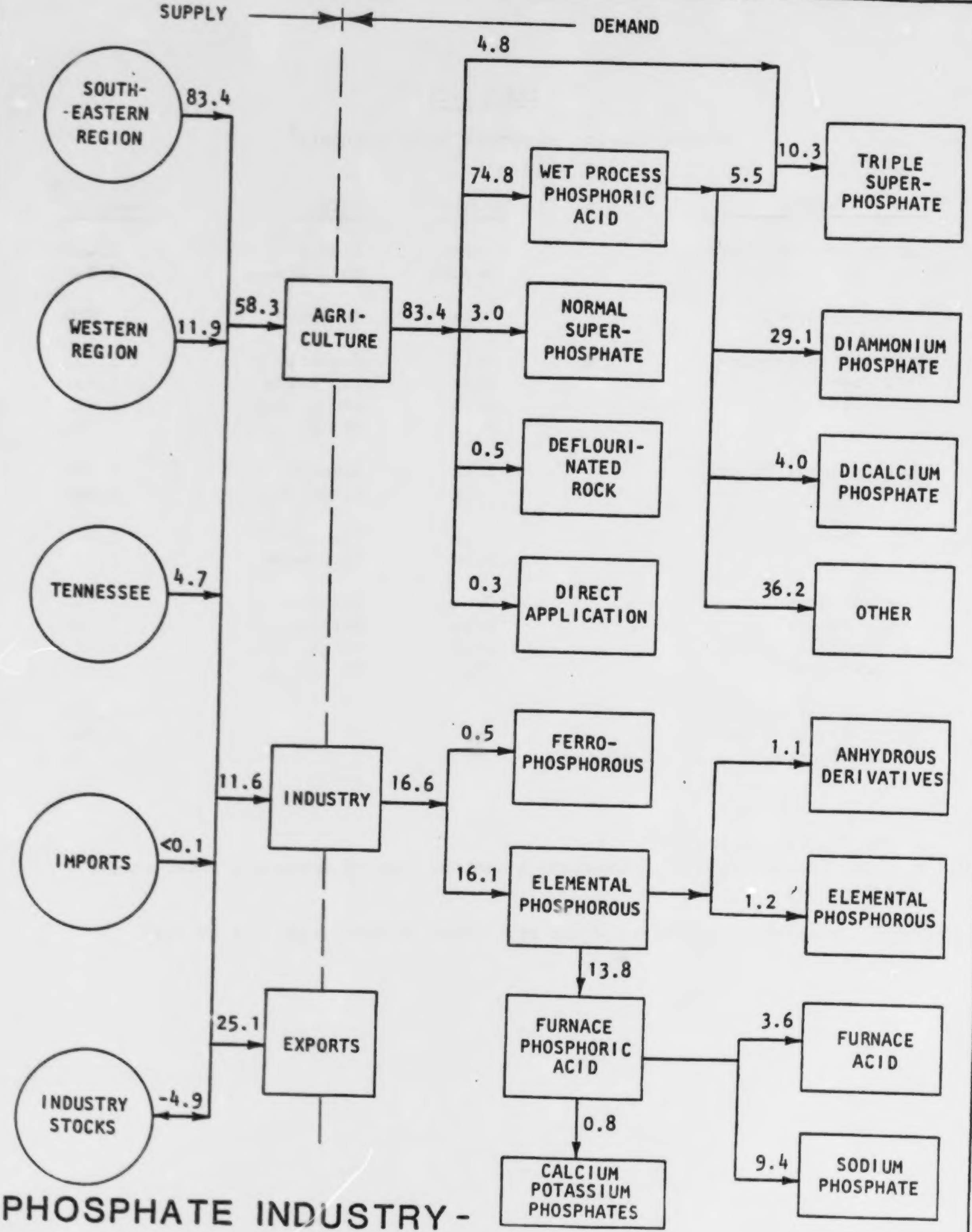
[a] From Reference 6-42.

[b] Plant capacities are in thousand of metric tons of phosphate rock, annual basis.

Note: Capacity is constant, while production changes from year to year.


SUPPLY
DEMAND
SOUTH-EASTERN REGION
83.4
WESTERN REGION
11.9
TENNESSEE
4.7
IMPORTS
<0.1
INDUSTRY STOCKS
-4.9
58.3
AGRI-CULTURE
83.4
11.6
INDUSTRY
16.6
25.1
EXPORTS
4.8
74.8
WET PROCESS PHOSPHORIC ACID
5.5
10.3
TRIPLE SUPER-PHOSPHATE
3.0
NORMAL SUPER-PHOSPHATE
29.1
DIAMMONIUM PHOSPHATE
0.5
DEFLOURI-NATED ROCK
4.0
DICALCIUM PHOSPHATE
0.3
DIRECT APPLICATION
36.2
OTHER
0.5
FERRO-PHOSPHOROUS
1.1
ANHYDROUS DERIVATIVES
16.1
ELEMENTAL PHOSPHOROUS
1.2
ELEMENTAL PHOSPHOROUS
13.8
FURNACE PHOSPHORIC ACID
3.6
FURNACE ACID
0.8
CALCIUM POTASSIUM PHOSPHATES
9.4
SODIUM PHOSPHATE

PHOSPHATE INDUSTRY -
SUPPLY & DEMAND IN 1975

[a] FROM REF 6-38. NUMBERS EQUAL PERCENT OF TOTAL SUPPLY (LEFT OF VERTICAL LINE) OR DEMAND (RIGHT OF LINE).

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FIGURE 6.11

## Ore Geology and Radionuclide Content

Economically workable phosphate rock deposits occur as sedimentary phosphates, in ingneous rocks, or as gauno or deposits derived from gauno.(6-39) Approximately 80% of world phosphate production and all phosphate rock mined in the United States is from sedimentary phosphorites.(6-38) The term "phosphorite" refers to marine phosphate deposits.(6-43) The geology of phospnate deposits in the three major producing areas will be discussed separately.

### Southeastern Region Phosphate Deposits

The phosphate rock deposits of Florida are classified as land pebble deposits (pebbles and fine phosphate sand dispersed in a non-phosphatic sandy clay), hard rock deposits (phosphate replaced limestone), soft rock deposits (phosphate sands and clays of the Alachua Formation), and river pebble deposits (phosphate nodules occurring in streams that have been winnowed from upstream or adjacent formations).(6-43, 6-44) Production in 1977 was predominantly from the land pebbles of the Bone Valley Formation in Polk, Hillsborough, and Hamilton Counties.

The Pilocene age Bone Valley Formation unconformably overlies the flat-lying Hawthorne Formation (also phosphate bearing) of Miocene age.(6-43) The lower and middle portions of the formation, which generally total 20 feet in thickness, are composed of poorly sorted clay, silt, and gravel.(6-43) Gravel is predominant. All of the gravel and much of the sand and clay is composed of a carbonate fluorapatite.

Phosphate values recoverable from the land-pebble deposits mined in Central Florida are currently confined to the sands (+150 mesh -1 mm) and pebbles (+1 mm). The clay fraction (-150 or 200 mesh) contains approximately one third of the total phosphate present in the ore matrix, but these values are at present not recoverable.

A description of the North Carolina phosphate deposits is provided by Gieseke (1977).(6-45) The North Carolina phosphate deposits are located in and around Beaufort County in the central coastal region of the state. Phosphate is mined from the middle Miocene age Pungo River Formation, which unconformably overlies the Castle Hayne Formation (the major regional aquifer) of Middle Eocene age. Phosphate granules in the Pungo River Formation range between 0.1 and 1.0 mm in diameter and are found in an unconsolidated matrix diluted by quartz sand, montmorillonite-type clay, calcium carbonate, and magnesium carbonate. A clean phosphate pebble typically averages 31% $P_2O_5$. The fluorapatite francolite is the principal phosphate-bearing mineral. The Yorktown Formation of late Miocene age unconformably overlies the Pungo River Formation. This unit is in turn overlain by Pliocene to Recent age sand layers.

### Western Region Phosphate Deposits

The phosphate ores of the western states are found chiefly in the marine Phosphoria Formation of Permian age. Potentially valuable phosphate deposits are spread over 130,000-135,000 square miles throughout Idaho, Utah, Wyoming, and Montana. Greater than 50% of the easily extractable reserves, however, are located within an 1,800 square mile area in southeastern Idaho where the phosphate beds are of greater thickness and grade. Present mining has focused on this region.(6-46)

Three members have been identified in the Phosphoria Formation. The basal and oldest Meade Peak Member is overlain by the Rex Chert followed by an unnamed cherty shale member. All of the economically recoverable phosphate reserves of southeastern Idaho are found in the Meade Peak phosphate shales. The strata have experienced substantial folding and faulting since deposition and are exposed by erosion in many places.

The four phosphatic shale beds of the Meade Peak Member have a total thickness of up to 15 feet, whereas the member varies in thickness between 60 and 200 feet with an average depth of 180 feet. In southeastern Idaho these beds are interbedded with limestones, siltstones and mudstone. The Meade Peak Member is partitioned on the basis of mining considerations into seven stratigraphic units. They are (in ascending order) the lower waste shale, lower high-grade ore, lower ore shale, middle waste shale, upper ore shale, upper high grade, and upper waste. The 5-6 foot thick lower high-grade ore unit is the most economically significant. It has an average $P_2O_5$ content of approximately 31% with some ore containing as high as 36% $P_2O_5$.

Western phosphate ore consists mainly of fluorapatite in oolitic form (i.e., as small pellets). The oolites are cemented by calcite and silica. Nodules composed of cemented pellets are sometimes greater than one inch in diameter.(6-46)

## Tennessee Phosphate Deposits

The Tennessee ores are classified as being blue, white or brown.(6-43) The blue rock occurs as unaltered portions of the Hardin sandstone member of the Chattanooga Shale (Devonian - Mississippian) and contains up to 32-34% $P_2O_5$. White rock occurs in irregular pockets and cavities in Silurian limestone. The larger deposits seldom exceed 28-30% $P_2O_5$. Brown rock ores occur as residual deposits formed by the action of groundwater on highly phosphatic Ordovician limestone.

## Ore Radionuclide Contents

Most phosphate deposits contain uranium series radionuclide concentrations that may be significantly elevated above the mean value for the earth's crust. The higher uranium levels are associated with marine-type deposits, which constitute all of the phosphate ores currently mined in the U.S. In these deposits the uranium substitutes for calcium in the phosphate.(6-47)

Domestic ores generally contain between 50 and 200 ppm uranium on a dry weight basis.(6-48) This corresponds to 17 to 66 pCi/g of uranium-238, which is in radioactive equilibrium with its daughter products, at least through radium-226. Natural thorium activity is in the general range of normal background values with concentrations ranging from 2 to 20 ppm (0.4-4 pCi/g). Florida ores are somewhat more radioactive than either Western or North Carolina ores, although the highest concentrations reported were in South Carolina phosphate. The lowest concentrations reported were in Tennessee phosphate rocks. More specific data on radionuclide contents of the ore and related materials are presented in the sections dealing with airborne radionuclide emissions.

## Process Description

### Southeastern Region Phosphate Operations (6-45)

The Florida land-pebble deposits chiefly consist of the following four zones:

Overburden - This layer is generally from 6 to 50 feet thick and consists mostly of topsoil, clay, and sand. It may contain phosphates, but in minor amounts not currently recoverable economically.

Matrix Ore - This zone contains the recoverable phosphates, mainly fluorapatite with silica sand and clay minerals. The ore zone is usually from 3 to 30 feet thick.

Bed Clay - This layer underlies the matrix and may contain minor phosphate values and limestone boulders.

Bedrock - This is usually a dolomitic limestone layer beneath the bed clay. The dolomite cannot be tolerated in the finished product.

The overburden is stripped by large electric draglines and stacked on natural ground level adjacent to the cut, or cast into a previously mined out cut. Rows of dams may be made with the overburden, the area between the dams being used for waste disposal or water reclamation.

The draglines also mine the matrix, which is deposited in a nearby sluice pit. Water from high pressure guns (200 psi) is used to break down the friable ore into a slurry. The slurried matrix is pumped through pipelines at about 20 to 50 percent solids to the washing plant, which is usually not more than three miles away.

The main function of the washer plant is to remove the phosphate bearing pebble from the matrix, and to disaggregate the ore in water so that it can be separated from the phosphate bearing fines. The components are separated by means of series of vibrating screens in closed circuit with hammer mills and log washers.

Phosphate bearing pebble ($\geq$ 1 mm) is sent to open storage piles directly by conveyor or by in-transit railroad cars. The product may also be temporarily stored in bins for drainage. The undersized material is passed through a series of cyclones for dewatering and desliming. The waste slimes (- 150 mesh) are sent to holding ponds for disposal, the contained phosphate values being currently unrecoverable. The intermediate sized sands (< 1 mm, $\geq$ 150 mesh) are transferred to the flotation mill for separating the phosphate minerals from the waste sand (tailings). Tailings may be slurried to separate sand piles, placed in mined-out areas, or used in the construction of dams to hold the slime ponds. The phosphate product is transferred to drainage bins and the drained concentrate (80 to 86%

solids) is sent to open wet-storage piles by conveyor. Some operations eliminate the drainage bins and send the concentrate directly to the storage piles.

The wet rock product, flotation concentrate or pebble is reclaimed from the storage piles by gravity-fed conveyors located in tunnels beneath the piles. The wet rock is dried in rotary or fluid bed dryers, conveyed to grinding mills, then sent to storage silos. From the silos, the dry rock is transferred to chutes for loading into freight cars for shipment. Final destination may be nearby chemical plants, port facilities for water transport to more remote plants in the U.S. or for export, or end use consumers. The rock also may be shipped wet, or dry (but not ground), for final drying and/or grinding at an intermediate or final facility. There are many possible combinations in current usage.

Operations in North Carolina are essentially the same as in Florida, with some minor differences. The overburden is thicker (100 feet), but so is the phosphate bearing matrix (40 feet). There is also more recoverable phosphate concentrate (4 to 8 times more per acre) and less slime (1/3 as much). The slimes also dewater more easily. Finally, the phosphate rock is completely processed at the mine site. Processing includes calcination of the rock at about 1500°F to remove unwanted hydrocarbons and to reduce the carbonate $CO_2$ content.

### Western Region Phosphates Operation

There are currently eight major phosphate producing mines in the Western Region; five in Idaho, and one each in Utah, Wyoming and Montana.(6-46) They are all open pit operations, with the exception of the Montana mine. The Idaho mining operations are given in Table 6-24, which shows the annual ore production capacity by mine and by grade, plus the destination of the ore. Approximately 40%

## TABLE 6-24

### Idaho Phosphate Mining Operations[d]

| Company/Mine | Ore Grade[a] | Ore Production MT/y | Ore Processing and/or Destination |
|---|---|---|---|
| 1. J.R. Simplot | | | |
| Gay[b] | acid | 540,000 | Shipped - Directly to the Simplots' fertilizer plant (Pocatello) |
| | furnace | 1,260,000 | Shipped - Directly to FMC's elemental P plant (Pocatello) |
| Conda[c] | acid | 180,000 | Shipped - Directly to FMC's elemental P plant (Pocatello) |
| | furnace | 1,020,000 | Milled - Acid grade concentrate produced<br>1) 27% calcined, sent to customer<br>2) 73% shipped to Simplots' fertilizer plant (Pocatello) |
| 2. Monsanto Co.<br>Henry | furnace | 900,000 | Shipped - Directly to Monsanto's elemental P Plant (Pocatello) |
| 3. Beker Industries<br>Mobie Canyon | acid | 2,500,000 | Processed - @ company's fertilizer plant (nearby) |
| 4. Stauffer Chemical<br>Wooley Valley | furnace | 680,000 | Shipped - Directly to company's elemental P plant (Silver Boro, Mont.) or to its beneficiation and calcining plant (Leefe, Wy) |

---

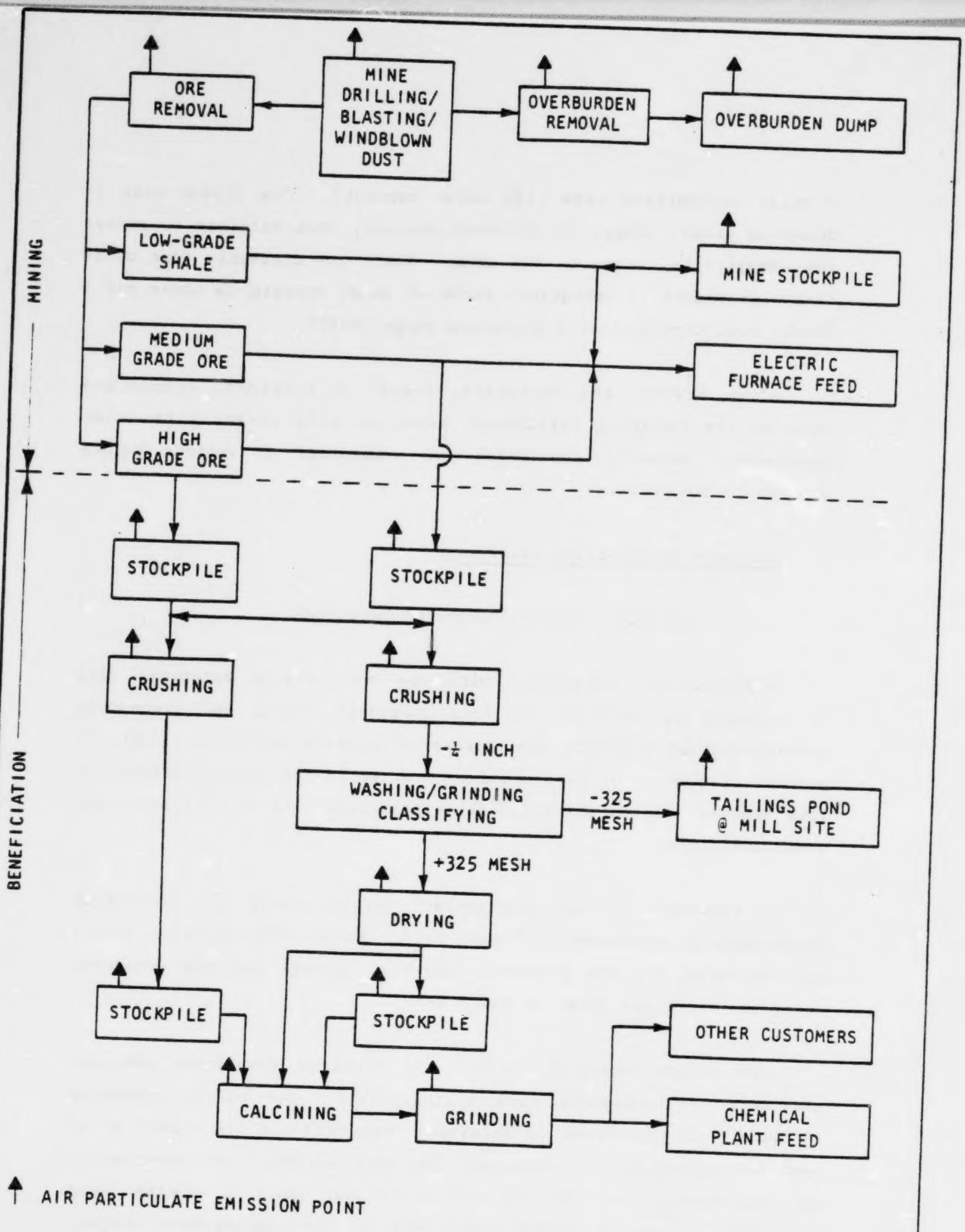
a Acid grade 31% $P_2O_5$, furnace grade 24-26% $P_2O_5$.
b Joint venture - J.R. Simplot and FMC Corporation.
c Three or four open pit operations.
d From Reference 6-46.

of the total production is processed into elemental phosphorus in one of three thermal-process plants operated by either FMC or Monsanto in Idaho, or Stauffer Chemical in Montana. The bulk of the ore is sent to wet process phosphoric acid fertilizer plants, with minor quantities sold directly to customers as beneficiated, calcined, and ground rock.

Mining methods differ from Southeastern Region operations since the mines are dry. Shovels, trucks and scrapers are used to remove the overburden, which may require blasting. Mining of the ore is accomplished with shovels, trucks, and front-end loaders, and sometimes scrapers. The ore is hauled by truck, conveyor, and railroad to mills or processing plants located either adjacent to the mines or relatively short distances away.

A generalized flowsheet of the various ore proccessing schemes is presented in Figure 6.12. The ore comes in three general grades depending on $P_2O_5$ content. High grade ores (>30 percent $P_2O_5$) are usually sent directly to phosphoric acid fertilizer plants, while medium grade ores (22-30 percent $P_2O_5$) must first be beneficiated to produce acid-grade plant feed. Calcining is generally required to burn off carbon in the ores due to its undesirable nature in phosphoric acid production. Medium grade ores may alternatively be sent directly to electric furnace plants for processing into elemental phosphorus (some high grade ore is also sent to electric furnace plants). Low grade shales (<22 percent $P_2O_5$) may be stockpiled at the mine site, blended with higher grade ores and beneficiated, or used directly as electric furnace feed. It should be noted that the above designations of ore grades are not precise and the $P_2O_5$ contents indicated are for rough classification only.

Beneficiation of western ores is basically a scrubbing and desliming operation. The ore is crushed, washed, ground, classified to remove -325 mesh material (slime tailings), and filtered to produce


ORE REMOVAL
MINE DRILLING/ BLASTING/ WINDBLOWN DUST
OVERBURDEN REMOVAL
OVERBURDEN DUMP
LOW-GRADE SHALE
MINE STOCKPILE
MEDIUM GRADE ORE
ELECTRIC FURNACE FEED
HIGH GRADE ORE
MINING
BENEFICIATION
STOCKPILE
STOCKPILE
CRUSHING
CRUSHING
-½ INCH
WASHING/GRINDING CLASSIFYING
-325 MESH
TAILINGS POND @ MILL SITE
+325 MESH
DRYING
STOCKPILE
STOCKPILE
OTHER CUSTOMERS
CALCINING
GRINDING
CHEMICAL PLANT FEED
AIR PARTICULATE EMISSION POINT

## IDAHO PHOSPHATES - MINING AND PROCESSING

Source: Reference 6-14

DAMES & MOORE

FIGURE 6.12

a moist concentrate cake (15% water content). The filter cake is dried in rotary driers to 3% water content, then calcined to remove the undesirable carbon in the ores. There are currently four beneficiation plants in operation, three of which operate as above and a fourth that incorporates a flotation stage.(6-45)

After drying, the phosphate product is calcined, ground and sent to the chemical fertilizer plant or sold directly to other customers. Material stockpiles are maintained at various points throughout the process.

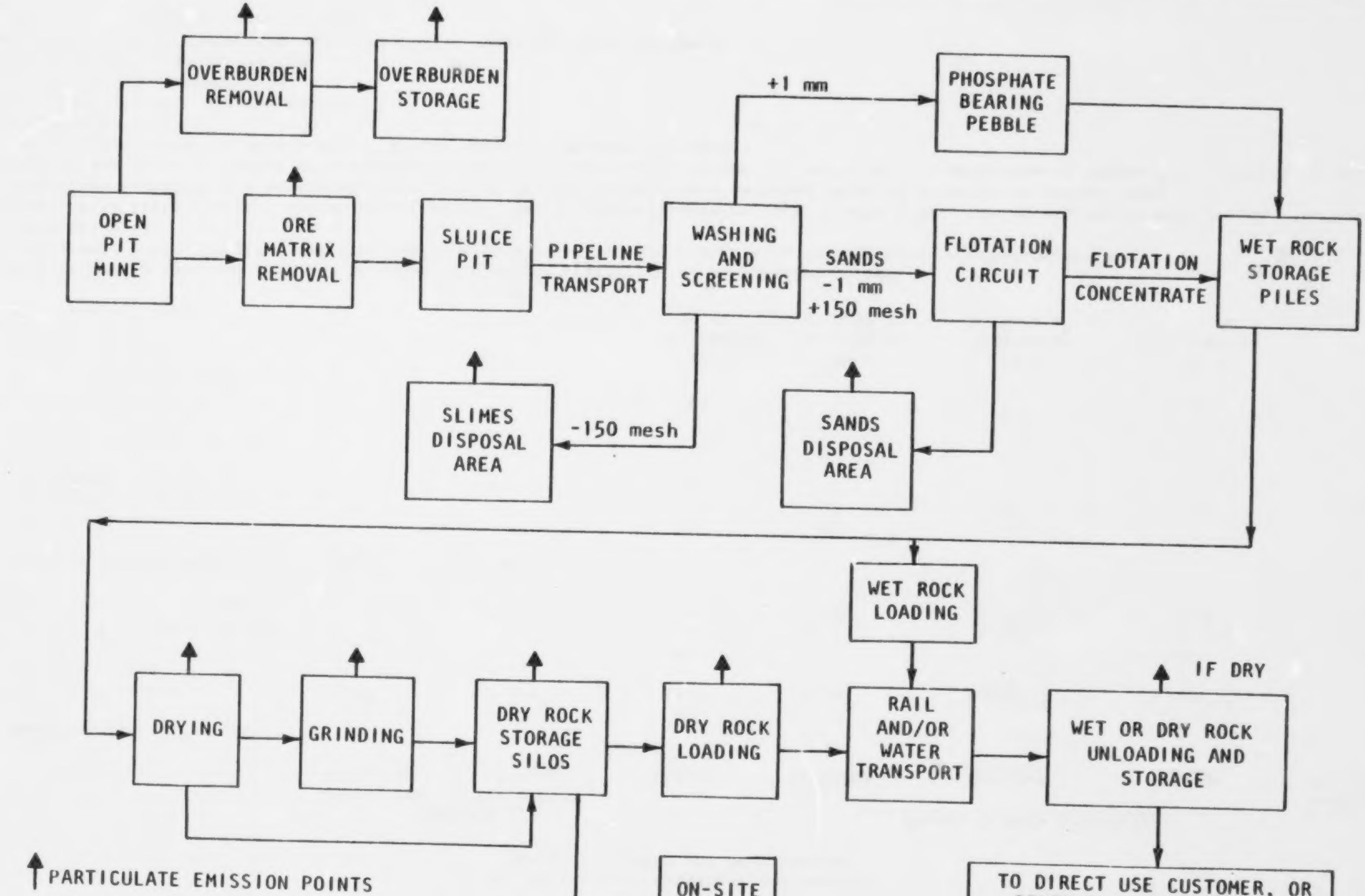
## Airborne Radionuclide Emissions

### Southeastern Region Phosphate Operations

Radionuclides associated with ore and related materials will be released as particulates from phosphate mining and processing operations that typically are sources of fugitive and process dust. A general discussion of dust emission sources is therefore presented in this section. Specific radionuclide emissions data will be presented where available.

A flowchart of the Southeastern Region mining and processing operations is presented in Figure 6.13. Particulate emission points are indicated for the process. Emission factors for the important emission points are given in Table 6-25.

Particulate emission factors for dragline operations are not available for phosphate rock mining.(6-41) The values presented in Table 6-25 are based on emissions from dragline operations at an open pit copper mine in Montana. The mine was moist and non-dusting and thus should yield results similar to what could be expected from the moist to wet phosphate operations in the Southeastern States. Radionuclide emissions would depend on the activity present in the


OVERBURDEN REMOVAL
OVERBURDEN STORAGE
OPEN PIT MINE
ORE MATRIX REMOVAL
SLUICE PIT
PIPELINE TRANSPORT
WASHING AND SCREENING
+1 mm
PHOSPHATE BEARING PEBBLE
SANDS
-1 mm
+150 mesh
FLOTATION CIRCUIT
FLOTATION CONCENTRATE
WET ROCK STORAGE PILES
SLIMES DISPOSAL AREA
-150 mesh
SANDS DISPOSAL AREA
WET ROCK LOADING
DRYING
GRINDING
DRY ROCK STORAGE SILOS
DRY ROCK LOADING
RAIL AND/OR WATER TRANSPORT
IF DRY
WET OR DRY ROCK UNLOADING AND STORAGE
ON-SITE PLANT
TO DIRECT USE CUSTOMER, OR DRYER AND/OR GRINDER, OR CHEMICAL PLANT, OR EXPORT
↑ PARTICULATE EMISSION POINTS

a - COMPILED FROM INFORMATION PRESENTED IN REFERENCES 6-38, 6-41, 6-44, 6-45.

SOUTHEASTERN REGION PHOSPHATE MINING AND PROCESSING

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FIGURE 6.13

# TABLE 6-25

## Air Particulate Emissions and Controls
## Phosphate Mining and Benefication

| Parameter | Dragline | | Phosphate Rock Activities | | | | |
|---|---|---|---|---|---|---|---|
| | Overburden Stripping | Ore Matrix Mining | Drying | Grinding | Transfer | Storage | Loading/ Unloading |
| I] Emission Factors[a] - g/MT | | | | | | | |
| A] Uncontrolled | 25[b] | 0.4[b] | 7500[c] | 10,000[c] | 1,000[c,d] | 1,000[c,d] | |
| B] Controlled | | | | | | | |
| 1. Ref 6-41 | | | 71 | | | 105 | 161 |
| 2. Ref 6-49 average[e] | | | 51 (21) | 40 (17) | 5 (20) | 22 (4) | 9 (3) |
| range | | | 3-211 | 1-24 | 0.2-12 | 1-29 | 1-16 |
| II] Control Devices Employed | None[f] | None[f] | | | | | |
| A] Wet Scrubbers[g] | | | 21 | 10 | 12 | 7 | |
| B] Fabric Filters[g] | | | | 16 | 9 | 8 | 15 |
| C] Other[g] | | | 1[h] | | | | 1[i] |
| III] Control Efficiencies - % | | | | | | | |
| A] Based on Ref 6-41[j] | | | 99.1 | | | 89.5 | |
| B] Based on Ref 6-49[j] | | | | | | | |
| 1. average | | | 99.3 | 99.6 | 99.5 | 97.8 | |
| 2. range | | | 97.2-99.96 | 98.8-99.99 | 98.8-99.98 | 97.1-99.9 | |
| C] From Ref 6-50 | | | 95-99 | 99.5-99.9 | 99.5-99.9[k] | | |

---

a Total particulate emission factors, in grams emitted per metric ton of material processed.

b From reference 5-41. Dragline emission based on data from open pit copper mine in Montana of similar conditions.

c From Reference 12.

d Reference 6-50 lists transfer and storage together, for a combined emission rate of 1000 g/MT. Listed separately here because information on controlled emissions was separated, thus each of the two uncontrolled emission rates is probably an overestimate.

e Average values based on number of individually identified waste gas streams for which data is presented in Tables 3-7. Numbers in parentheses indicate number of data points. Ranges presented beneath averages.

f From reference 6-41.

g From reference 6-49. See Tables 3-7.

h Wet electrostatic precipitator.

i Dust collectors, unspecified type.

j Calculated based on controlled and uncontrolled emissions reported above.

k Transfer and storage reported together.

materials associated with the ore deposit. Topsoil may be slightly elevated above background due to deposition of daughter radionuclides from radon-222, which may diffuse upward from the ore body at rates higher than background.(6-51) Other non-ore fractions would contain uranium series activity similar to those reported for a typical profile from the Central Florida Phosphate District.(6-51) In this profile, uranium-238 activity was in the range of 5.6 to 8.4 pCi/g in the sand (upper) portion of the overburden, 28 to 84 pCi/g in the leached zone (lower) portion of the overburden, 5.6 to 42 pCi/g in the bed clay underlying the ore matrix, and less than 2.8 pCi/g in the bedrock. The ore matrix itself contained from 28 to 56 pCi/g of uranium-238 activity in its raw state. Activity concentrations of particulate emissions from dragline operations, or windblown dust from material storage, would thus be equivalent to the concentrations in the material involved.

Once the matrix enters the sluice pit the processing operations involve only wet or slurried material. Therefore, there are no particulate emissions until the phosphate concentrate and/or pebble product enters the dryer.

The drying, dry product grinding, storage and handling, loading and shipping operations all contribute to particulate emissions from the phosphate industry. Many of these emission points are currently controlled to reduce emissions and emission parameters are reported to a controlling government agency. In Florida, most companies must report these parameters to the Florida Department of Environmental Regulations on an annual basis. Air particulate emission data reported by various companies in 1976 are presented in Tables 6-26 to 6-30 for five emission points.(6-49) These tables give the phosphate rock processing rate, operating schedule, plus the total particulate emissions for 1976. In addition, the emissions per metric ton of phosphates processed are presented to indicate the relative effectiveness of the control device employed at that emission point. No

## TABLE 6-26

### Phosphate Rock Drying

| Company Name - Plant | Process Rate$^{a}$ MT/h | Operating Schedule$^{b}$ h/y | Particulate Emissions$^{c}$ Total MT | Particulate Emissions$^{c}$ Unit g/MT | Control Technology$^{d}$ |
|---|---|---|---|---|---|
| 1. Agrico Chemical Co.<br>Pierce Dry Mills | 116<br>112 | 4115 | 58.4 | 122.8 | Wet Scrubber |
| | 196 | 4338 | 65.1 | 48.7 | Wet Scrubber$^{e}$ |
| 2. Borden, Inc.<br>Tenoroc | 176 | 3233 | 32.4 | 57.0 | Wet Scrubber |
| 3. Brewster Phosphates<br>Lonesome Dry Mill$^{f}$ | 410<br>410 | 2103<br>2106 | 2.6<br>14.3 | 3.0<br>16.5 | Wet Scrubber<br>Wet Scrubber |
| 4. Conserv, Inc.<br>Nichols | 63 | 4667 | 45.1 | 154.1 | Cyclones, Wet Scrubber, Fabric Filters |
| 5. Gardinier, Inc.<br>Fort Meade | 243 | 7957 | 83.0 | 43.0 | Wet Scrubber |
| 6. W.R. Grace & Co.<br>Ridgewood Dry Mill | 209<br>104 | 5625 | 40.8 | 23.2 | Wet Electrostatic Precipitator$^{e}$ |
| 7. IMC Chemicals Corp.<br>New Wales | 280 | 7500 | 95.3 | 45.3 | Wet Cyclone Scrubber |
| 8. Int. Min. & Chem. Corp.<br>Kingsford$^{g}$ | 283 | 6484<br>15000$^{c}$ | 53.5<br>2.7 | 29.2<br>0.6 | Wet Cyclone Scrubber<br>Wet Pack Scrubber |
| Noralyn$^{g,h}$ | 213 | 6688<br>4444 | 92.5<br>3.6 | 64.9<br>3.8 | Wet Cyclone Scrubber<br>Wet Pack Scrubber |
| | 304 | 6378<br>6267 | 53.5<br>42.6 | 27.6<br>22.4 | Wet Cyclone Scrubber<br>N/A |

## TABLE 6-26 (cont'd)

### Phosphate Rock Drying

| Company Name - Plant | Process Rate[a] MT/h | Operating Schedule[b] h/y | Particulate Emissions[c] Total MT | Particulate Emissions[c] Unit g/MT | Control Technology[d] |
|---|---|---|---|---|---|
| Port Sutton Terminal | 265 | 5811 | 69.6 | 45.2 | Cyclones(2) & Wet Scrubber |
| 9. Mobil Chemical Co | | | | | |
| Nichols | 42 | 1649 | 14.8 | 211.4 | Wet Scrubber |
| | 218 | 7173 | 44.8 | 28.4 | Venturi Scrubber |
| | 225 | 7048 | 32.1 | 20.2 | Venturi Scrubber |
| | 46[i] | 7266 | 35.0 | 105.6 | Venturi Scrubber |
| 10. Swift Agricultural | | | | | |
| Agricola | 127 | 5654 | 49.8 | 69.4 | Wet Scrubber |
| | 229 | 5260 | 35.8 | 29.8 | Wet Scrubber |
| 11. USS Agri-Chemicals | | | | | |
| Bartow | 181 | 720 | 4.1 | 31.2 | Wet Scrubber - Two Stage |
| Fort Meade | 114 | 5100 | 33.1 | 56.9 | Wet Scrubber |

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a Process rate in metric tons/hour dry phosphate rock.
b Calculated, based on reported annual emissions divided by average hourly emissions. Discrepancy not clarified if >8760 hours.
c Total emissions reported for 1976, in metric tons. Unit rate is grams of particulates emitted per metric ton of product.
d As listed on data sheets.
e Control device handles combined waste gas streams.
f Opened 6-1-76.
g Volume distribution of waste gas stream from process not specified.
h Combined emissions from drying and product transferrance.
i Phosphate rock calcining.

## TABLE 6-27

### Phosphate Rock Grinding

| Company Name - Plant | Process Rate[a] MT/h | Operating Schedule[b] h/y | Particulate Emissions[c] Total MT | Particulate Emissions[c] Unit g/MT | Control Technology[d] |
|---|---|---|---|---|---|
| 1. Agrico Chemical Co. | | | | | |
| South Pierce | 55.3 | 3953 | 1.5 | 7.0 | Wet Scrubber |
| 2. Borden, Inc. | | | | | |
| Piney Point | 76.3 | 6598 | 8.7 | 17.3 | Fabric Filter |
| | 2.2 | 1341 | 2.1 | 711.6 | Fabric Filter |
| 3. Gardinier, Inc. | | | | | |
| East Tampa | 152.4 | 8792 | 2.1 | 1.6 | Fabric Filter |
| | 31.8 | 6912 | 6.4 | 29.1 | Fabric Filter |
| | 49.9 | 7474 | 1.3 | 3.5 | Fabric Filter |
| | 25.2[e] | 8789 | 4.5 | 20.5 | Fabric Filter |
| 4. W.R. Grace & Co. | | | | | |
| Bartow Works | 40.6 | 7760 | 8.8 | 27.9 | Fabric Filter |
| | 95.0 | 6800 | 13.9 | 21.5 | Fabric Filter |
| | 26.4 | 4152 | 5.4 | 49.6 | Wet Scrubber |
| Ridgewood | 19.4 | 2800 | 3.2 | 58.4 | Wet Scrubber |
| 5. Int. Min. & Chem. Corp. | | | | | |
| Kingsford[f] | 31.6 | 7234 | 30.8 | 135.1 | Venturi Scrubber |
| | | 7467 | 5.1 | 21.6 | Venturi Scrubber |
| Noralyn[f] | 38.6 | 6667 | 1.8 | 7.1 | Fabric Filter |
| | | 6438 | 9.3 | 37.6 | Fabric Filter |
| | | 6500 | 11.8 | 47.1 | Fabric Filter |
| | | 6476 | 6.2 | 24.7 | Fabric Filter |
| | | 6556 | 5.4 | 21.2 | Fabric Filter |
| 6. Mobil Chemical Co. | | | | | |
| Nichols | 43.3 | 2683 | 6.0 | 51.2 | Wet Scrubber |
| | 43.7 | 2680 | 12.7 | 108.9 | Wet Scrubber |

## TABLE 6-27 (cont'd)

### Phosphate Rock Grinding

| Company Name - Plant | Process Rate[a] MT/h | Operating Schedule[b] h/y | Particulate Emissions[c] Total MT | Particulate Emissions[c] Unit g/MT | Control Technology[d] |
|---|---|---|---|---|---|
| 7. Royster Co. | | | | | |
| Mulberry | 62.7 | 7000 | 0.9 | 2.0 | Fabric Filter |
| 8. Swift Agricultural | | | | | |
| Agricola | 13.6 | 3148 | 3.4 | 79.0 | Wet Scrubber |
| | 9.1 | 3149 | 2.0 | 70.5 | Wet Scrubber |
| | 13.6 | 3150 | 5.3 | 124.0 | Wet Scrubber |
| 9. U.S.S. Agri-Chemicals | | | | | |
| Bartow | 94.8 | 1368 | 0.1 | 0.9 | Fabric Filter |
| Fort Meade[g] | N/A | 6167 | 0.7 | N/A | Fabric Filter |

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[a] Process rate in metric tons/hour dry phosphate rock.

[b] Calculated, based on reported annual emissions divided by average hourly emissions. Discrepancy not clarified if >8760 hours.

[c] Total emissions reported for 1976, in metric tons. Unit rate is grams of particulates emitted per metric ton of product.

[d] As listed on data sheets.

[e] Includes storage.

[f] Volume distribution of waste gas stream from process not specified.

[g] Includes rock feed.

N/A Not Available.

## TABLE 6-28

### Phosphate Rock Transfer

| Company Name - Plant | Process Rate[a] | Operating Schedule[b] | Particulate Emissions[c] | | Control Technology[d] | Product Description[d] |
|---|---|---|---|---|---|---|
| | MT/h | h/y | Total MT | Unit g/MT | | |
| 1. Agrico Chemical Co. | | | | | | |
| Pierce Dry Mills | 309 | 4336 | 7.0 | 5.2 | Wet Scrubber | Dry Phosphate Rock |
| | 424 | 4337 | 9.9 | 5.4 | Wet Scrubber | |
| | 309 | 342 | <0.1 | 0.4 | Wet Scrubber | |
| | 309 | 4339 | 12.7 | 9.5 | Wet Scrubber | |
| | 424 | 4333 | 3.1 | 1.7 | Wet Scrubber | |
| | 424 | 4336 | 4.3 | 2.4 | Wet Scrubber | |
| 2. Gardinier, Inc. | | | | | | |
| East Tampa | 78 | 7834 | 7.3 | 11.9 | Fabric Filter | |
| | 78 | 7828 | 2.1 | 3.4 | Fabric Filter | Ground Phosphate Rock |
| | 132 | 7834 | 7.3 | 7.0 | Fabric Filter | |
| | 132 | 8000 | 2.0 | 1.9 | Fabric Filter | |
| | 132 | 7952 | 4.5 | 4.2 | Fabric Filter | |
| | 132 | 8000 | 0.6 | 0.6 | Fabric Filter | |
| | 18 | 6851 | 1.5 | 11.9 | Fabric Filter | Phosphate Rock |
| 3. W.R. Grace & Co. | | | | | | |
| Bartow Works | 372 | 3600 | 8.3 | 6.2 | Wet Scrubber | Phosphate Rock Conveyors |
| | 372 | 3600 | 8.3 | 6.2 | Wet Scrubber | |
| | 372 | 3333 | 0.5 | 0.4 | Fabric Filter | |
| Ridgewood Dry Mill | 291 | 3700 | 8.4 | 7.8 | Wet Scrubber | Dry Rock Conveyors |
| | 291 | 4000 | 1.4 | 1.2 | Wet Scrubber | |

## TABLE 6-28 (cont'd)

### Phosphate Rock Transfer

| Company Name - Plant | Process Rate[a] MT/h | Operating Schedule[b] h/y | Particulate Emissions[c] Total MT | Unit g/MT | Control Technology[d] | Product Description[d] |
|---|---|---|---|---|---|---|
| 4. IMC Chemicals Corp. New Wales | | | | | | |
| | 293 | 7500 | 1.4 | 0.6 | Wet Scrubber | Dry Rock |
| | 293 | 8000 | 0.4 | 0.2 | Wet Scrubber | |
| | N/A | 7385 | 4.4 | N/A | Fabric Filter | Phosphate Rock |

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a Process rate in metric tons/hour dry phosphate rock.

b Calculated, based on reported annual emissions divided by average hourly emissions. Discrepancy not clarified if >8760 hours.

c Total emissions reported for 1976, in metric tons. Unit rate is grams of particulates emitted per metric ton of product.

d As listed on data sheets.

N/A Not Available.

## TABLE 6-29

### Phosphate Storage

| Company Name - Plant | Process Rate[a] MT/h | Operating Schedule[b] h/y | Particulate Emissions[c] Total MT | Particulate Emissions[c] Unit g/MT | Control Technology[d] | Product Description[d] |
|---|---|---|---|---|---|---|
| 1. Borden, Inc.<br>Piney Point | N/A | 196 | 0.2 | N/A | Fabric Filter | Phosphate Rock Storage |
| 2. Brewster Phosphates<br>Lonesome Dryer | N/A | 2087 | 0.4 | N/A | Wet Scrubber | Dry Rock Storage |
| 3. W.R. Grace & Co.<br>Ridgewood Dry Mill | 106 | 4000 | 0.4 | 1.1 | Wet Scrubber | Phosphate Rock Storage |
| | 159 | 3400 | 15.4 | 28.6 | Wet Scrubber | |
| | 159 | 3400 | 15.4 | 28.6 | Wet Scrubber | |
| | 159 | 3400 | 15.4 | 28.6 | Wet Scrubber | |
| | N/A | 5429 | 4.3 | N/A | Fabric Filter | Dry Rock Storage |
| 4. IMC Chemicals Corp.<br>New Whales | N/A | 7500 | 5.4 | N/A | Fabric Filter | Dry Rock Silo |
| | N/A | 7442 | 14.5 | N/A | Fabric Filter | Dry Rock Silo |
| | N/A | 7385 | 4.4 | N/A | Fabric Filter | Dry Rock Bin |
| | N/A | 7385 | 4.4 | N/A | Fabric Filter | Dry Rock Bin |
| 5. USS - Agri - Chemicals<br>Bartow | N/A | 692 | <0.1 | N/A | Wet Scrubber | Dry Rock Storage |
| | N/A | 1460 | <0.1 | N/A | Fabric Filter | Rock Feed Storage |
| Fort Meade | N/A | 3232 | 14.5 | N/A | Wet Scrubber | Rock Storage |
| | N/A | N/A | 0.8 | N/A | Fabric Filter | Rock Storage |

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[a] Process rate, in metric tons/hour product processed

[b] Calculated, based on reported annual emisssions divided by average hourly emissions. Discrepancy not clarified if >8760 hours.

[c] Total emissions reported for 1976, in metric tons. Unit rate is grams of particulates emitted per metric ton of product.

[d] As listed on data sheets.

N/A Not Available

TABLE 6-30

Phosphate Loading/Unloading Activities

| Company Name - Plant | Process Rate[a] MT/h | Operating Schedule[b] h/y | Particulate Emissions[c] Total MT | Particulate Emissions[c] Unit g/MT | Control Technology[d] | Product Description[d] |
|---|---|---|---|---|---|---|
| 1. Borden, Inc. Piney Point | 80 | 6760 | 8.7 | 16.1 | Fabric Filter | U - 68 BPL Rock[f] |
| | N/A | 2286 | 0.1 | N/A | Fabric Filter | U - Ground Rock |
| 2. C.F. Chemicals, Inc. Bonnie | 133 | 8800 | 0.8 | 0.7 | Dust Collector | U - Rock |
| 3. Farmland Ind., Inc. Green Bay[g] | 183 | 9026 | 1.6 | 1.0 | Wet Scrubber | Phosphate Rock Unloading and Storage |
| | | 9200 | 0.2 | 0.1 | Fabric Filter | |
| | | 10000 | 0.1 | <0.1 | Fabric Filter | |
| | | 10714 | 0.1 | <0.1 | Fabric Filter | |
| | | 11111 | 0.1 | <0.1 | Fabric Filter | |
| | | 12500 | 0.1 | <0.1 | Fabric Filter | |
| | | 8851 | 0.9 | 0.6 | Fabric Filter | |
| | | 8851 | 0.9 | 0.6 | Fabric Filter | |
| | | 8936 | 0.4 | 0.2 | Fabric Filter | |
| | | 8829 | 0.9 | 0.6 | Fabric Filter | |
| | | 8795 | 0.7 | 0.4 | Fabric Filter | |
| | | 8848 | 0.7 | 0.4 | Fabric Filter | |
| 4. IMC Chemicals Corp. New Whales | N/A | 7444 | 24.3 | N/A | Fabric Filter | U - Ground Phosphate Rock |
| 5. Int. Minerals & Chem. Port Sutton Terminal | 631 | 3333 | 20.4 | 9.7 | Dry Cyclones(6) & Wet Scrubber | U - Phosphate Rock and Chemicals |
| | 1486 | 2701 | 9.4 | 2.4 | Fabric Filter | L - Phosphate Rock and Chemicals |

---

a. Process rate, in metric tons/hour product processed.
b. Calculated, based on reported annual emissions divided by average hourly emissions. Discrepancy not clarified if >8760 hours.
c. Total emission reported for 1976, in metric tons. Unit rate is grams of particulates emitted per metric ton of product.
d. As listed on data sheets.
e. U = unloading, L = loading.
f. 68% Bone Phosphate of Lime.
g. Volume distribution of waste gas stream from process not specified.

judgements can be made concerning the effectiveness of individual devices, however, since no engineering data (gas volume, inlet loading, temperature, etc.) are presented. Each control device is listed as reported by the company, hence details of the device are lacking. The unit emission rates have been averaged for each of the five processes and results included in Table 6-25 to show the relative importance of each controlled source.

Controlled emission factors presented in Table 6-25 for phosphate rock activities are from two sources. The factors from reference 6-41 were based on measurements of ground level particulate concentrations downwind of the source. Six sample runs were made at one site during a week-long program. Cyclones and wet scrubbers were employed on the drying and storage operation, but no control device was in use at the loading station, although it was enclosed. The factors from reference 6-49 are the averages and ranges from Table 6-26 to 6-30. In reference 6-49, only controlled emission points are reported, thus contributing to the large discrepancy in emission factors for loading and unloading operations reported for each reference. The other factors agree reasonably well considering the limited data on which they are based.

The distribution of radionuclides in the three major fractions of phosphate ore matrix are presented in Table 6-31. The uranium series nuclides appear to be in radioactive equilibrium through radium-226 in all three fractions. The distribution among fractions indicates that 45% of the uranium series activity is present in the marketable rock, 49% in the slimes and 6% in the sand tailings.

Ore processing activities (drying, grinding, etc.) would yield particulate emissions with radionuclide concentrations characteristic of the marketable rock. For example, phosphate drying, which results in a controlled release of approximately 50 grams of particulates per metric ton of dry rock produced, would yield an average

## TABLE 6-31

Radium-226, Uranium and Thorium Concentrations in Florida Phosphate Mine Products and Wastes[a]

| Material | Radium-226 | Uranium |  |  | Thorium |  |  |  | Uranium Series[b] |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 234 | 235 | 238 | 227 | 228 | 230 | 232 | Total | % |
| Marketable Rock | 42 | 41 | 1.9 | 41 | 2.0 | 0.6 | 42.3 | 0.4 | 168.2 | 45 |
| Slimes | 45 | 42 | 2.6 | 44 | 2.3 | 1.2 | 48 | 1.4 | 181.6 | 49 |
| Sand Tailings | 7.5 | 5.2 | 0.4 | 5.3 | 2.2[c] | 0.9[c] | 4[d] | 0.9[d] | 22.4 | 6 |
| TOTAL | 94.5 | 88.2 | 4.9 | 90.3 | 4.3 | 1.8 | 94.3 | 2.7 | 372.2 | 100 |

---

[a] From Ref 6-47. Concentrations in pCi/gram.

[b] Total equals combined activity of uranium-234, 235, 238, radium-226, and thorium-230. Percentage shows percent of total uranium series activity in that material fraction.

[c] Rough approximation calculated by averaging contents of marketable rock and slimes. Based on similarity with Thorium-232 distribution, which appears to be an average even though it is a measured value.

[d] From Ref 6-51.

of 2050 pCi of uranium-238 per metric ton of dry product, or 8410 pCi for the combined uranium series (as defined in Table 6-31). Thorium-227, 228, and 232 emissions would be much lower, yielding a combined emission rate of 150 pCi per metric ton of dry product.

Stack sampling was performed by the EPA (6-52) on a phosphate rock dryer equipped with a wet scrubber. Results showed that 50% of the activity was contained in particles below 8.2 um median aerodynamic diameter and was roughly equatable to mass distribution. Thus activity concentrations are not a function of particle size in phosphte dryer emissions. Data of this type could not be found for other phosphate processing operations. Polonium-210 emissions have also been estimated for drying, grinding and shipping of triple super phosphate (6-52) based on analyzed samples. Similar data could not be found for marketable phosphate rock.

Additional particulate emission sources may exist due to the waste sands and slimes from the beneficiation process. The clay wastes leave the washer plant as cycle overflow or thickener underflow at about 3 to 5 percent solids content. It takes approximately two years in settling ponds to reach a 25 percent solids content, and 5 to 20 years for reclamation to support agricultural uses or small structure development (single family dwellings).(6-51) Waste volumes are large requiring roughly 50 percent more settling volume than exists in the mined-out pit, thus resulting in total settling areas of 30 to 60 percent of the mined land (to date, approximately 130,000 acres have been strip mined in Florida). Before reclamation is completed at a particular mine site, the settling pond surface layer may dry out and result in the generation of windblown dust. Overburden material would also be a source of windblown dust.

Radon-222 is also emitted at various stages in the processing cycle. Areas containing material with elevated radium-226 concentrations, such as overburden and waste piles, reclaimed land, and exposed ore matrix (in an active mine) would constitute area sources of radon-222 with emanation rates above what is normally considered to be background (0.01 to 1.0 $pCi/m^2$-sec). Processing operations, such as drying, grinding, and closed storage, would also produce radon emissions. Drying and grinding would rapidly release radon that would otherwise diffuse out slowly or not at all. Closed storage may allow buildup of relatively high levels of radon and daughter products within the closed structure, resulting in a more concentrated stream of emissions.

### Western Region Phosphate Operations

Particulate emissions from Western phosphate operations are generated throughout the mining and ore processing industry. Figure 6.12 indicates most of the important sources. Additional sources not shown include fugitive emissions from road haulage, and the various loading, unloading and transfer steps incorporated in the material flow process.

Specific particulate emissions data for most of the Idaho phosphate operations were not readily available. However, emissions should generally be greater than for Florida phosphate operations due mostly to the greater quantities and drier nature of the overburden removed during open pit operations. A more realistic emission factor for overburden removal would be about 50 g/MT, or about twice that for Florida operations.(6-41) Ore matrix removal could similarly be assumed to generate 0.8 g/MT removed, also about twice that of the corresponding Florida process.

Transfer, unloading, stockpiling, drying, and grinding should exhibit particulate emission factors similar to those of Florida operations (Table 6-25). The calcination process is an additional operation, although North Carolina phosphates are also calcined. A specific emission factor for phosphate calcining, performed using a variety of calciners, could not be found.

Measurements of radionuclide concentrations in phosphate ore and calcined rock have been reported for two processing plants in Idaho, the J.R. Simplot Wet Process Plant near Pocatello (Ref 6-53) and the FMC Corporation Thermal Process Plant, also near Pocatello (Ref 6-54). Results of these measurements are summarized in Table 6-32. Results reported for samples taken at the J.R. Simplot plant are not very consistent, the radionuclide content of calcined ore being higher than for the input ore for many of the nuclides. Also, errors were discovered in the analysis of the Pb-210 and Po-210 content in J.R. Simplot samples that indicate that uncertainties in the reported values are up to an order of magnitude for those two nuclides. An input/output balance is therefore difficult to discern for the J.R. Simplot samples.

Samples are more consistent in the results reported for FMC Corporation. They indicate little difference in the radionuclide contents of the calciner input and output materials. The exceptions are Po-210 and Pb-210 which are volatized to some degree in the calcining process. The extent of the loss is not known precisely due to problems involved in sample analysis. However, it appears that approximately 20% of the Po-210 is lost through the calciner stack. Some Po-210 and perhaps half of the Pb-210 is apparently lost to liquid streams (e.g., scrubber liquids). A summary of the material and radionuclide balance for the calciner process is presented in Table 6-33 for the FMC plant. Material flow rates are given on an hourly basis and should be multiplied by 8760 hours to obtain the annual rates based on a continuously operating process. The calciner effluents are for downstream of the coolers or scrubbers.

## Airborne Radionuclide or Particulate Emission Controls

### Southeastern Region Phosphates

There are currently no controls in use to specifically limit

## TABLE 6-32

Radionuclide Content of Selected Idaho Phosphate Samples[a]

| Radionuclide | Calciner Input - Phosphate Ore | | | | Ore Calciner Product | |
|---|---|---|---|---|---|---|
| | J.R. Simplot Corp. Plant | | | FMC Plant[b] | J.R. Simplot | FMC[b] |
| | Conda Mine (Low Grade Ore) | Conda Mine (Main Bed Ore) | Gay Mine (High Grade Ore) | Gay Mine (Unspecified Ore) | | |
| Ra-226 | 32±1.0 | 28±0.97 | 28±0.96 | 26±19 | 38±1.1 | 25±8.6 |
| Po-210[d] | 48±5.9 | 32±3.4 | 35±3.4 | 22±3.0 | 42±6.2 | <2.6 |
| U-234 | <15 | 39±30 | 28±8.1 | 22±2.0 | 64±5.0 | 23±2.2 |
| U-235 | < 8.8 | <9.2 | <1.6 | 0.95±0.40[c] | 1.4±0.38 | 1.0±0.24[c] |
| U-238 | 18±16 | <20 | 26±7.5 | 22±3.2 | 38±3.2 | 24±1.8 |
| Th-230 | 56±4.1 | 45±6.6 | 44±7.7 | 22±4.1 | 65±3.2 | 23±2.0 |
| Th-232 | 1.9±1.7 | <1.3 | 2.9±2.3 | 0.43±0.12 | 0.40±0.27 | 0.47±0.10 |
| Pb-210[d] | 1.9±0.62 | 12±0.96 | 7.9±0.84 | 27±12 | 9.0 ±0.89 | 18±8.6 |
| Ra-228 | <0.86 | <0.95 | 1.1±0.96 | 0.89±0.28 | <0.96 | 0.97±0.48 |

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a All results in pCi/g ± 2σ counting error. Data extracted from tables in references 6-53 and 6-54.

b Pb-210 and Po-210 results are average values for samples analyzed by one laboratory. All others are averages of values reported by two laboratories.

c U-235 value calculated based on U-238 activity.

d Difficulties encountered in analysis of J.R. Simplot samples for Pb-210 and Po-210 indicate up to an order of magnitude uncertainty in values reported for Simplot samples.

## TABLE 6-33

### Material and Radionuclide Balance - FMC Plant Calciner[a]

| Material | Radionuclide Concentration[b] | Material Flow Rate | Total Annual Activity (Curies) |
|---|---|---|---|
| Phosphate Ore | (pCi/g) | 180 MT/h | |
| U | 22±3 | | 36±5 |
| Ra-226 | 26±19 | | 42±31 |
| Pb-210 | 27±12 | | 44±19 |
| Po-210 | 22±3 | | 36±5 |
| Calcined Rock | (pCi/g) | 160 MT/h | |
| U | 24±2 | | 33±3 |
| Ra-226 | 25±8.6 | | 34±12 |
| Pb-210 | 18±8.6 | | 24±12 |
| Po-210 | <2.7±2.7 | | <4±4 |
| Stack Effluents[c] | (pCi/$m^3$) | 0.35x$10^6$ $m^3$/h | |
| U | 14±1 | | 0.04 ±0.003 |
| Ra-226 | 1.7±0.3 | | 0.005±0.001 |
| Pb-210 | 3.2±0.6 | | 0.01 ±0.002 |
| Po-210 | 61±6 | | 0.2 ±0.02 |
| Calciner Scrubber[c] | (pCi/$m^3$) | 0.46x$10^6$ $m^3$/h | |
| U | 0.31±0.10 | | 0.001±0.0003 |
| Ra-226 | 0.31±0.16 | | 0.001±0.0005 |
| Pb-210 | 0.86±0.5 | | 0.003±0.002 |
| Po-210 | 1700±140 | | 6.9 ±0.6 |

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[a] From reference 6-54. Calcining process is a continuous operation at this plant.

[b] Net Pb-210 and Po-210 values are based on 0.1 pCi of activity per blank filter. The U results are an average of the U-234 and U-238 results. Less than values have been assumed to be equal to the less than value.

[c] All volumes are in terms of dry standard cubic meters. There are four calciner cooler and scrubber stacks that are similar. The flow rate shown is the total.

radionuclide emissions from the phosphate industry. Controls do exist to limit particulate emissions, thus radioactivity associated with the particulates are also reduced. Radon release may also be reduced by some of these controls. A general discussion of particulate controls is provided below.

The control technologies currently employed to limit particulate emissions from phosphate operations are presented in Table 6-25. Phosphate drying operations almost exclusively employ various types of wet scrubbers, and loading and unloading of dry phosphate rock primarily use fabric filter systems. The grinding, transfer and storage operations do not show a strong preference for either type of device, although in general fabric filter systems appear to be a better choice due to the ease of product recovery and higher fine particulate collection efficiency, costs and other considerations not being taken into account. Control efficiencies for total particulates are also presented in Table 6-25. The data are from three separate sources yet they agree reasonably well. The low value of 89.5% under storage based on reference 6-41 is probably due to the fact that no control device was employed at that point, although the storage system was enclosed. In general, controls exhibit a collection efficiency of better than 97 percent for total particulates, and in some cases exceed 99.9 percent.

In the mining operations, overburden removal and ore matrix mining by dragline methods are currently uncontrolled sources of air particulate emissions. Furthermore, no control techniques are planned (6-41) since the generally wet nature of these operations naturally limit emissions, and additional control techniques are essentially non-existent.

Windblown dust from waste pile surfaces are controlled ultimately through reclamation of the mine site. No controls are employed to limit dusting from slime ponds prior to reclamation due to the fact that the moist nature of the ponds (40 percent to 50 percent solids at point of reclamation) tend to naturally reduce dusting.

It should be noted that certain process modifications recently recommended by the U.S. EPA (6-51) would reduce airborne particulate emissions from phosphate operations. One method involves elimination of the phosphate dryer, substituting wet rock grinding and processing. This would all but eliminate particulate emission after the dragline operations. A second process modification would reduce the potential dusting from waste piles. This method involves mixing the tailings with clay slimes to produce a mixture with a solids content varying from 50 to 90 percent, resulting in landfill suitable for reclamation within two years. Consequently, exposure to dust generating winds would be reduced.

Radon emissions are controlled in part due to reclamation activities. Covering of waste material (slimes) with overburden containing less radium tends to reduce radon emanation rates. Mixing of slimes with lower activity sands reduces the activity concentration of radium-226 and thus results in reduced radon emanation.

### Western Region Phosphates

As previously mentioned, no controls are employed by the phosphate industry to limit radionuclide releases. Thus any radionuclide control is a consequence of particulate emission control.

Information on the control equipment at four western phosphate plants (two thermal process plants and two wet process plants) was obtained from the Idaho Department of Health and Welfare (6-55). This information is presented in Table 6-34. The table gives the type of control, control efficiency, and total particulate emissions for five major process categories. Information on calciner controls was

## TABLE 6-34

### Particulate Control Technology - Western Region Phosphates[a]

| Process Description | Plant | Control Equipment Description | Control Equipment Efficiency % | Controlled Emissions[b] t/y |
|---|---|---|---|---|
| Ore Crushing | 1 | 3 Baghouses | 99.4 | 4 |
| Ore Drying | 4 | Cyclone/Cyclonic Spray Scrubber | 99.0 | 104 |
| Ore Calcining<br>Kiln | 1[c] | Medium Efficiency Scrubbers | 85.0 | 340 |
| | 2 | Large Spray Tower | 99.9 | 21 |
| | 3[d] | #1 - High Efficiency Cyclone & High Efficiency Scrubber | 99.9 | 3 |
| | | #2 - Medium Efficiency Cyclone & High Efficiency Scrubber | 99.6 | 28 |
| | | #3 - Medium Efficiency Cyclone & High Efficiency ESP | 99.8 | 57 |
| | 4[e] | Cyclones/Venturi Scrubber | 99.5 | 160 |
| Cooler | 1[c] | Settling Chamber<br>Note: Additional controls are being required | | 234 |
| | 2 | Large Spray Tower | 99.9 | 21 |
| Calciner Product Grinding<br>Crushing/screening<br>Roller Mills | 2[f] | Venturi Scrubber | 99.9 | 6 |
| | 3[f] | Medium Efficiency Cyclones & Medium Temperature Fabric Filters | 99.0 | 17 |
| Ball Mills | 4[g] | Baghouses | 99.8 | 8 (est.) |

## TABLE 6-34 (cont'd)

### Particulate Control Technology - Western Region Phosphtes[a]

| Process Description | Plant | Control Equipment Description | Control Equipment Efficiency % | Controlled Emissions[b] t/y |
|---|---|---|---|---|
| Calciner Product Handling | | | | |
| Nodule Reclaim | 1[h] | Baghouses | 99.0 | 10 |
| Nodule Transfer | 1[i] | Baghouses | 98.5 | 13 |
| Storage Bins | 4[j] | Baghouses | 99.8 | 2 |

---

[a] From Ref 6-55.

[b] Total annual emissions. Emissions from multiple processes are summed.

[c] Two calciners in operation. Each calciner employs two scrubbers for kiln exhausts and two settling chambers for cooler exhausts. Emissions are total for all four devices for each type of exhaust.

[d] Three separate calciners employed. Each employs different controls.

[e] Three calciners. Each separate calciner exhaust is treated by cyclones/venturi scrubber combination.

[f] Three similar control combinations treat exhausts from three sets of mills: set 1, two mills; set 2, one mill; set 3, three mills.

[g] Two ball mills. Each exhaust treated by one baghouse.

[h] Reclaim for two separate nodule stockpiles. Each exhaust treated by one baghouse.

[i] Two separate transfer operations, each treated by a baghouse.

[j] Unspecified number of storage bins, one baghouse.

available for all four plants, while other process categories were limited to as little as one plant. Thus, plant process schemes vary sufficiently to limit the usefulness of comparisons among the four plants.

Nevertheless, general observations are possible based on the limited data. Ore crushing and calciner product grinding and handling activities are controlled mainly by fabric filter systems whereas ore drying and calcining operations employ, almost exclusively, various types of wet scrubbers, usually following a low efficiency precleaner such as a cyclone. The exceptions are one calciner that employs an ESP to treat kiln exhausts, and one plant that uses only low efficiency settling chambers to treat calciner cooler gases.

It is difficult to compare calciner kiln emission controls due to the wide variety of calciners employed. Plant 1 calcines pre-formed briquettes using a chain grate calciner, plant 2 calcines nodules in a rotary kiln, and plant 3 employs one fluidized bed calciner. Two other calciners used at plant 3 and three calciners from plant 4 are of an unspecified type. The various calciners result in a range of different emission characteristics and control equipment requirements.

## The Bauxite Industry

### Industry Description

The aluminum industry in the United States is the primary consumer of domestic and imported bauxite and alumina*. Approximately 89 percent of the aluminum bearing raw material consumed in 1976 was used to produce aluminum metal. The remaining 11 percent was used as bauxite or alumina in non-metal applications (abrasives, refractory materials, chemicals, and other alumina products).

Domestic bauxite mining is centered in Arkansas, which produced approximately 84 percent of the total 1977 U.S. output of 2,000,000 metric tons.(6-56) The Arkansas ore supplies two alumina production plants in the state. The remaining 15 percent came from Alabama and Georgia, where the ore was used in the production of refractories and chemicals.

Imported bauxites supplied about 88% of the U.S. bauxite demand in 1976 ( by aluminum content). Most of the bauxite was processed in 9 alumina production plants, which had a combined capacity of 3,687,000 metric tons (aluminum equivalent) of alumina. An additional 1,705,000 metric tons (aluminum equivalent) of alumina were imported. In all, only about 8 percent of the aluminum produced in the U.S. originates from domestic mines.

Figure 6.14 presents an overview of the industry. The origin of the ore is presented along with the principal refineries, their locations and annual production capacities (in thousands of metric tons aluminum equivalent).

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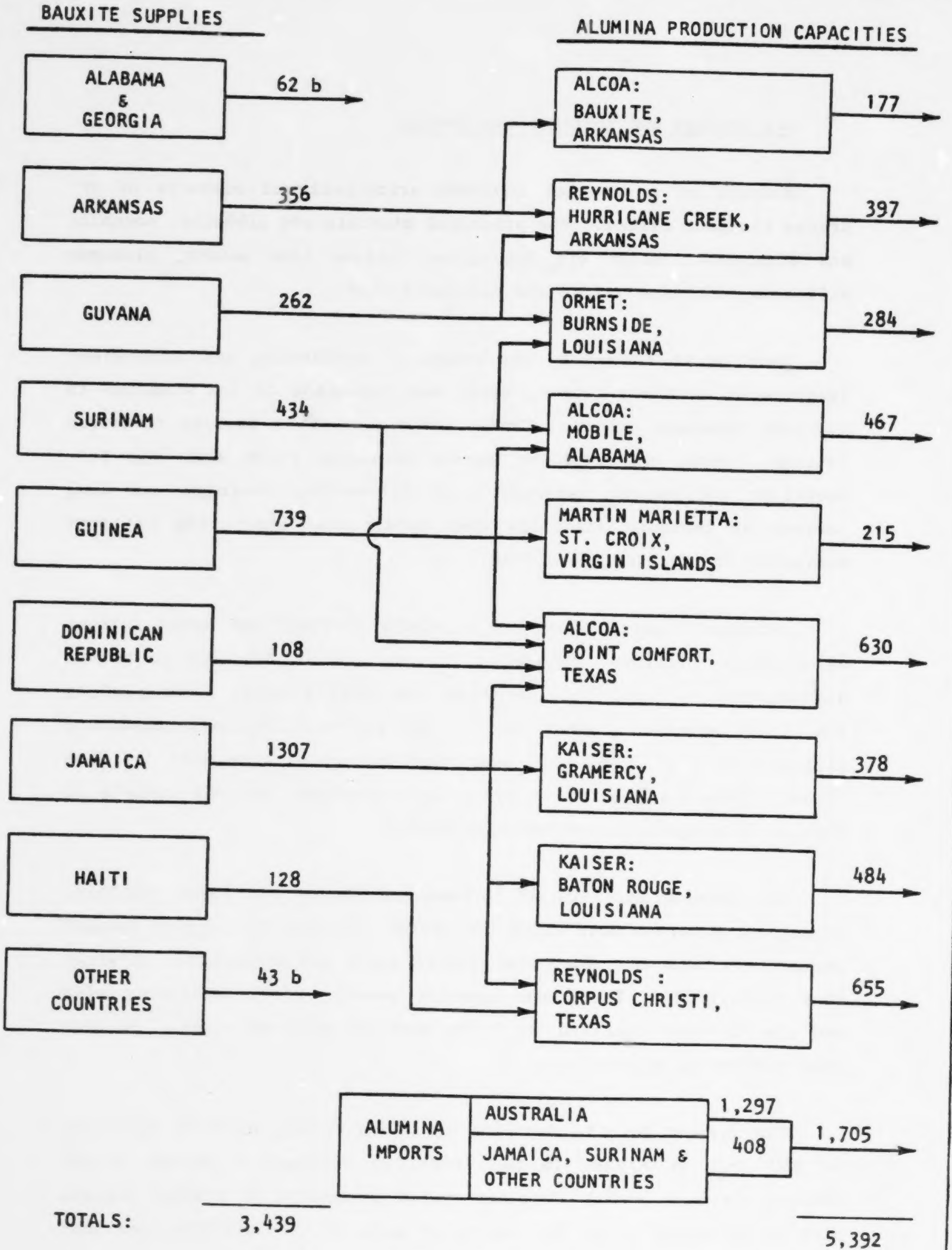
*Alumina (Aluminum Trioxide) is pre-metal refined bauxite.


BAUXITE SUPPLIES
ALUMINA PRODUCTION CAPACITIES
ALABAMA & GEORGIA
62 b
ARKANSAS
356
GUYANA
262
SURINAM
434
GUINEA
739
DOMINICAN REPUBLIC
108
JAMAICA
1307
HAITI
128
OTHER COUNTRIES
43 b
ALCOA: BAUXITE, ARKANSAS
177
REYNOLDS: HURRICANE CREEK, ARKANSAS
397
ORMET: BURNSIDE, LOUISIANA
284
ALCOA: MOBILE, ALABAMA
467
MARTIN MARIETTA: ST. CROIX, VIRGIN ISLANDS
215
ALCOA: POINT COMFORT, TEXAS
630
KAISER: GRAMERCY, LOUISIANA
378
KAISER: BATON ROUGE, LOUISIANA
484
REYNOLDS : CORPUS CHRISTI, TEXAS
655
ALUMINA IMPORTS
AUSTRALIA
1,297
JAMAICA, SURINAM & OTHER COUNTRIES
408
1,705
TOTALS:
3,439
5,392

ALUMINA INDUSTRY

a. FROM REF. 6-56 FIGURES IN THOUSAND METRIC TONS ALUMINUM EQUIVALENT
b. UNSPECIFIED DISTRIBUTION

**DAMES & MOORE**

FIGURE 6.14

## Ore Geology and Radionuclide Content

Bauxite is a material composed principally of mixtures of hydrated aluminum oxides. The principal minerals are gibbsite, boehmite and diaspore. Major ore impurities include iron oxides, aluminum silicates, titanium oxides and kaolinite clay.

Bauxite is formed by the chemical weathering and subsequent leaching of aluminum bearing rocks and retention of the aluminum in hydrated aluminum oxides. Conditions conducive to bauxite formation include: warm, wet climates, parent aluminous rocks with high permeability and soluble minerals; good sub-surface drainage; and long periods of tectonic stability that permit deep weathering and preservation of land surfaces.(6-56)

Jamaican bauxite occurs on a middle Tertiary age karst surface as sinkhole fillings, channel fillings, and as blankets on uneven depressions. Individual bauxite ore bodies range from pockets containing several hundred tons of ore to basin fillings containing millions of tons. The soil overlying the deposits is only 1-2 feet thick. Jamaican bauxite is typically gibbsitic, but may contain as much as 20 weight percent boehmite.(6-56)

The bauxite deposits of Surinam and Guyana are found scattered throughout a narrow belt along the contact between Tertiary or younger sedimentary beds that form the coastal plain and Precambrian crystalline rock.(6-56) These ore deposits mostly overly kaolinitic clay and are in turn overlain by 0-200 feet of sand and clay. Bauxite from Surinam is gibbsitic.

The largest bauxite deposits of inland Guinea occur at altitudes of 900 feet or higher in the lateritic cappings of stream valley divided plateaus.(6-56) Tertiary period weathering of a large diabase sill is believed to be the source of much of the laterite (red host soil). Guinea bauxite is gibbsitic.

Domestic bauxite ores are gibbsitic. The major central Arkansas deposits are Eocene in age and were formed by weathering of an igneous intrusion. Bauxite occurs as blankets on the weathered surface or as transported deposits. Most of the deposits are covered by overburden. The bauxite deposits of the coastal plain of Alabama and Georgia are found as lenses within flat lying kaolinite deposits overlain by sand and clays of early Tertiary age.(6-56)

The concentrations of uranium and thorium in bauxite are generally substantially larger than those of average crustal rocks and are related to the concentrations of the assumed parent rocks. The uranium and thorium concentrations of a worldwide suite of 29 bauxite samples were determined by J.A.S. Adams and K.A. Richardson (1960). (6-57) These bauxites represented a range of presumed parent rocks: acid igneous, basic igneous, shale and limestone. Uranium concentrations ranged from 2.7-26.7 ppm (1.8-17.8 pCi/g), with an average concentration of 11.4 ppm (7.6 pCi/g). Thorium concentrations ranged from 5.0-131 ppm with an average concentration of 48.9 ppm. The ratios of the thorium to uranium concentration ranged from 1.5-20.9, with an average value of 5.1. Acidic igneous derived bauxites were found to contain greater uranium and thorium concentrations than bauxite originating from any other rock type. Bauxite derived from basic igneous rocks had the lowest uranium and thorium concentrations. Table 6-35 summarizes the uranium concentrations, thorium concentrations, and U/Th concentration ratios for bauxites from selected localities.

A study of the uranium and thorium content of a suite of Arkansas drill core and weathering sequence bauxite samples was also conducted by the same authors.(6-57) The uranium content, thorium content, and thorium/uranium concentration ratio of the 13 bauxite core samples ranged from 4.8-8.8 ppm, 24.5-94.8 ppm, and 4.5-12.7, respectively. Transported bauxite samples had uranium contents, thorium contents, and ,thorium/uranium concentration ratios that were not substantially

## TABLE 6-35

### Uranium and Thorium in Selected Bauxites*

| Location | Number of Samples | Average Uranium Concentration (ppm) | Average Thorium Concentration (ppm) | Concentration Ratio Thorium/Uranium |
|---|---|---|---|---|
| Jamaica | 2 | 16.5 | 35.8 | 2.2 |
| Surinam | 2 | 10.3 | 73.1 | 7.1 |
| Guinea | 1 | 24.1 | 127.4 | 5.3 |
| United States | | | | |
| Arkansas | 2 | 17.1 | 103.3 | 6.0 |
| Georgia | 2 | 14.5 | 40.8 | 2.8 |

---

* From Reference 6-57.

different than those for bauxites overlying the parent rock. The large lateral variations in the bauxite uranium and thorium content were found over distances of only a few feet for the weathering sequence samples, with no apparent change in texture or vertical position in the deposit. Adams, et. al., concluded from bauxite and process sample studies that much of the thorium and uranium in bauxite reside in either primary or secondary resistate minerals.(6-57)

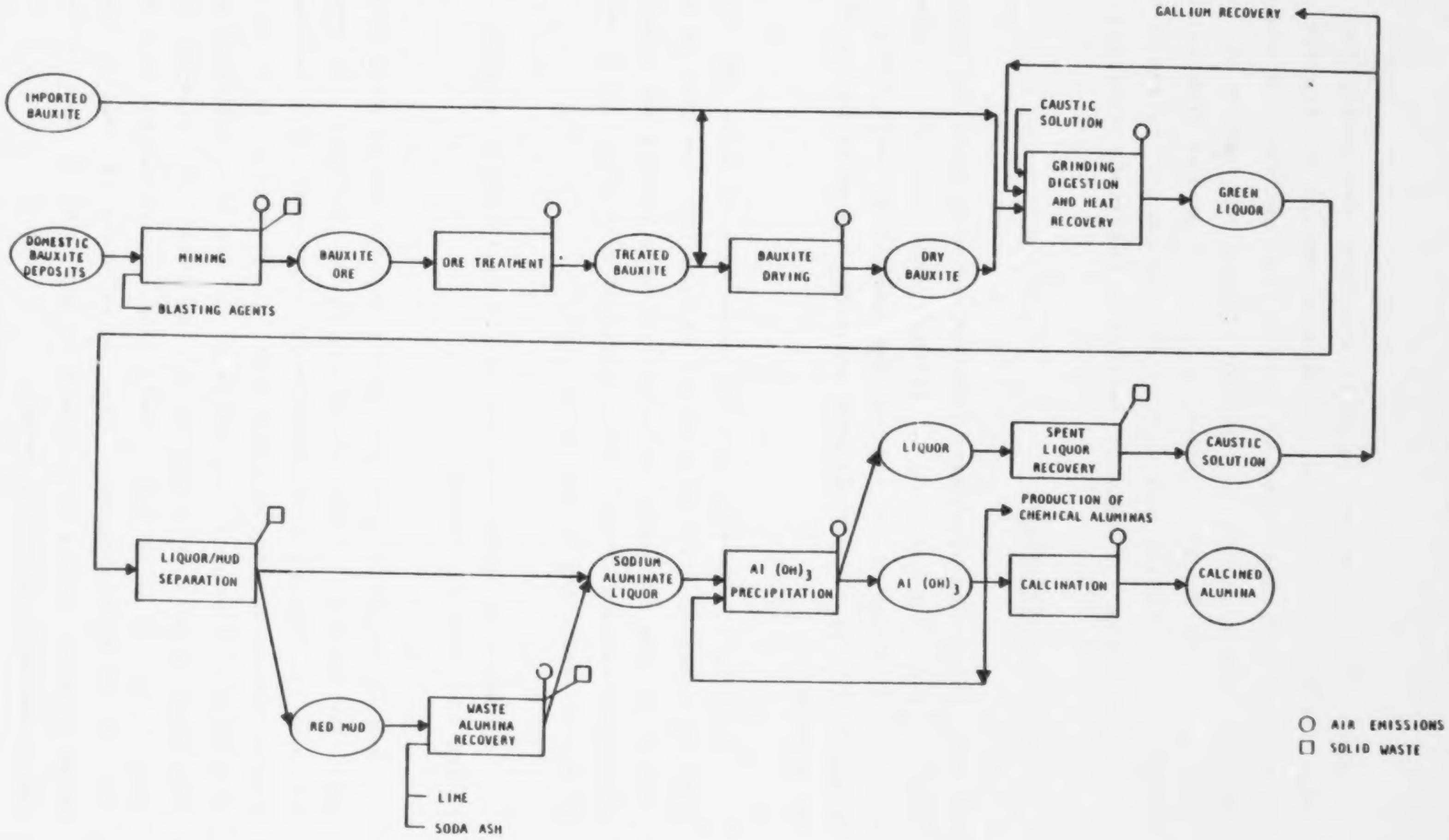
## Process Description

The production of alumina involves the mining and benficiation of bauxite ore, and refining of alumina from bauxite. Figure 6.15 presents a flowsheet of the various operations incorporated in the process, with sources of airborne emissions and solid wastes indicated by symbols.

In 1976, 12 domestic open pit mines were in operation. Only two open pit mines in Arkansas produced bauxite that was used in aluminum production, the remaining ten mines producing bauxite for chemical and refractory alumina.(6-58) One underground mine exists in Arkansas but it was not operating at the end of 1976.

It should be noted that much of the following information appears in EPA 600/2-77-023y (6-59).

Current domestic open pit mining methods employ draglines, shovels, and haulers. After the overburden is stripped, the bauxite is loosened by blasting with low-strength explosives, then excavated and transported to an ore treatment area. Stripping ratios of as much as 13 meters of overburden to one meter of ore are considered minable, thus large amounts of overburden are produced. For example, in 1975, about 4 tons of solid waste (waste rock and overburden) were produced per ton of bauxite mined. This solid waste is usually stored in heaps adjacent to the pits, where it may later be used in refilling and recontouring mined-out areas.


GALLIUM RECOVERY
IMPORTED BAUXITE
CAUSTIC SOLUTION
GRINDING DIGESTION AND HEAT RECOVERY
GREEN LIQUOR
DOMESTIC BAUXITE DEPOSITS
MINING
BLASTING AGENTS
BAUXITE ORE
ORE TREATMENT
TREATED BAUXITE
BAUXITE DRYING
DRY BAUXITE
LIQUOR
SPENT LIQUOR RECOVERY
CAUSTIC SOLUTION
PRODUCTION OF CHEMICAL ALUMINAS
LIQUOR/MUD SEPARATION
SODIUM ALUMINATE LIQUOR
Al (OH)3 PRECIPITATION
Al (OH)3
CALCINATION
CALCINED ALUMINA
RED MUD
WASTE ALUMINA RECOVERY
LIME
SODA ASH
○ AIR EMISSIONS
☐ SOLID WASTE

# FLOWSHEET - THE PRODUCTION OF ALUMINA FROM BAUXITE

Source: Reference 6-59

FIGURE 6.15

Bauxite ore treatment is a relatively simple operation. The crude ore is crushed to a size of about five centimeters, then classified (screened) to remove silica and clay. Spiral concentrators and magnetic separators may be used to remove iron minerals.

Bauxite ore is dried if it contains more than about 30% moisture, which is the upper limit allowable in the refining process. Imported ores are dried before shipment and thus do not usually require drying after importation.

The dried bauxite ore is ground to approximately 100 mesh, then mixed with caustic solution in large mixing tanks to produce a slurry containing from 12 to 16 percent sodium hydroxide by weight. The slurry is processed in a digester (pressure vessel or autoclave) at elevated temperatures and pressures which causes the formation of sodium aluminate. The resultant aluminum bearing solution is called "green liquor".

The green liquor is next separated from undissolved solids by a variety of thickeners, mud washers, and clarifying filters. This can be a complex process since the particles may be very fine, sometimes less than one micrometer in size. The final separation stage is a continuous filter press which removes all insoluble solids from the sodium aluminate liquor. The filtered liquor is pumped directly into precipitators for further processing. The waste solids (called "red mud") are pumped to a disposal site, or in some cases to an additional alumina recovery step.

The red mud slurry represents a major waste product of alumina production. The slurry contains between 17 and 25 percent insoluble solids and must be contained in holding ponds constructed at the processing plant. The ponds are simply diked lakes, the dikes being constructed of mixtures of readily available sand and clay. These ponds may range in size from 40 to 800 hectares in order to contain

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## Airborne Radionuclide or Particulate Emissions

No data could be found concerning airborne radionuclide emissions from bauxite mining and processing operations. As radioactive particulate emissions may be qualitatively correlated with particulate materials, a discussion of particulate emissions follows.

In the bauxite mining operation, airborne particulates are emitted during blasting, overburden removal, ore loading and hauling, and by wind blowing across the mine area and overburden piles. Specific emissions factors for bauxite mining are not available from direct measurements, although emission factors are available from similar operations (e.g., iron mining). In general, open pit mining produces about 0.25 kilograms of particulates per metric ton of bauxite mined.

Crushing and conveying of ore are sources of particulate emissions. The emission rate ranges from 0.5 to 4 kilograms released per metric ton of bauxite feed. The crushed ore is further ground, generating an additional 3.0 kilograms of airborne particulates per metric ton of bauxite processed. The combined emissions from the crushing/conveying/grinding stages are thus in the range of 3.5 to 7.0 kilograms per metric ton.

Once the ground bauxite is mixed with caustic solution, the process is wet and hence no further particulate emissions (other than mists) are expected to occur until the alumina precipitate is dried and calcined. The only exception is the windblown dust that can originate from the surfaces of dried out waste piles.

The alumina calcination process represents the main source of potential air pollution in bauxite refining. Approximately one metric ton of water is discharged through the stack for every metric ton of alumina produced. The vapor carries with it approximately 100 kilograms of fine alumina particles per metric ton of product, or 10% of the alumina processed.

Particulate emission factors are summarized in Table 6-36 for the five most important emission sources. Both controlled and uncontrolled emission factors are presented, along with the types and efficiencies of the appropriate control devices. The nature of the material being emitted (i.e., the parent material) is also specified for each process.

The natural radionuclide concentrations of the various materials associated with the above particulate emissions from the alumina production process have been assessed by Adams.(6-37) Samples were analyzed that represented seven days of operation for each of two alumina plants sampled. One plant processed ore from Surinam and the other from Arkansas. Results are presented in Table 6-37. The table presents a mass balance for the input/ output materials for the two plants, although about 0.4 kilograms are not accounted for in the output from plant 1. The classifier sand is the coarser fraction of red mud, which is removed from the mud thickeners to reduce the load. The separation of red mud and coarse sand is not exact.

As seen from Table 6-37, most of the uranium and thorium input to the process is deposited with the red mud. Classifier sands may also retain a small percentage of these elements. The calcined alumina product also contains very little uranium and thorium, exhibiting concentrations on the order of normal background for soils. Although alumina calcining is the most important source of particulate emissions, it is not the most important source of radionuclide emissions based on the data presented. Operations emitting particles consisting of ore or red mud are the primary radionuclide emitters. Particulate control devices employed to control those sources would thus be controlling the emissions of material enhanced in radionuclide concentration.

Assuming radioactive equilibrium in the uranium decay chain, radon emissions may be expected from the processing of bauxite. The

## TABLE 6-36

### Particulate Emissions and Controls - Bauxite Mining and Processing[a]

| Source | Particulate Emissions | | | Control Technology | |
|---|---|---|---|---|---|
| | Uncontrolled kg/MT | Controlled[b] kg/MT | Material | Efficiency % | Type of Control |
| 1. Open Pit Mining | 0.25 | 0.1 | Ore | 50[c] | Water Sprays |
| 2. Crushing/Conveying | 0.5-4 | 0.005-0.04 | Ore | >99[c] | Fabric Filters |
| 3. Grinding | 3.0 | N/A | Ore | N/A | Low Energy Wet Scrubbers |
| | | 0.5 | | 83 | Quench Tower & Spray Screen[d] |
| | | 0.06 | | 98 | Electrostatic Precipitator[d] |
| 4. Waste Piles | N/A | N/A | Red mud/ brown mud | N/A | Reclamation |
| 5. Calcining | 100 | -- | Alumina | -- | Multicyclones followed by: |
| | | 2 | | 98 | Electrostatic Precipitator |
| | | <1 | | >99[c] | Fabric Filter |

---

[a] All information from reference 6-59, unless otherwise specified.
[b] Calculated, based on estimated efficiency of control.
[c] Estimate from reference 6-60.
[d] Listed as potentially applicable device in reference 4.

N/A Not Available.

## TABLE 6-37

### Thorum and Uranium Contents - Input/Output Material From Alumina Production[a]

| Material Component | Material Balance[b] | Radionuclide Content |  |  | Alpha Activity[c] | Distribution[d] |  |
|---|---|---|---|---|---|---|---|
|  |  | Th | U | Th/U |  | Th | U |
|  |  | ppm | ppm | ratio | counts/hr | % | % |
| I] Surinam Ore |  |  |  |  |  |  |  |
| A. Bauxite | 1.9 | 74.2 | 3.6 | 20.9 | 342 |  |  |
| B. Calcined alumina | 1.0 | 4.9 | 0.3 | 14.7 | 1.1 | 3.5 | 5 |
| C. Fine red mud | 0.48 | 281 | 11.6 | 24.2 | 1332 | 96 | 82 |
| D. Classifier sand | 0.05 | 122 | 10.1 | 11.9 | 629 | 4.3 | 7.4 |
| II] Arkansas Ore |  |  |  |  |  |  |  |
| A. Bauxite | 2.25 | 75.8 | 19.8 | 3.8 | 346 |  |  |
| B. Calcined alumina | 1.0 |  |  |  | 0.8 |  |  |
| C. Fine red mud | 1.04 | 120 | 39.8 | 2.8 | 750 | 73 | 93 |
| D. Classifier sand | 0.22 | 70.1 | 6.4 | 11.0 | 318 | 9.1 | 3.1 |

---

[a] Taken from reference 6-57. Analyses by gamma ray spectrometry, except for alpha.

[b] Kilograms of material input or output per kilogram of alumina produced.

[c] Results in counts per hour from sample surface of 20.3 $cm^2$.

[d] Numbers indicate percent of total elemental input (bauxite content) contained in that ouput component.

most important aspect of radon emissions, however, would be the radon emanating from red mud waste ponds. Table 6-37 shows a value of 39.8 ppm uranium in red mud from Arkansas ore. This would correspond to about 13 pCi/g of radium-226, which is on the order of ten times contiguous U.S. background. Radon emissions from these piles are not controlled other than by the water present in the pond, which greatly suppresses radon diffusion.

## Airborne Radionuclide or Particulate Emission Controls

Controls are not employed to limit radionuclide emissions from the alumina industry. Therefore, a discussion of particulate control technology follows.

The control of fugitive emissions from the open-pit mining of bauxite ore is usually accomplished through the use of water sprays. Water is applied on an as needed basis, although quantitative data on its effectiveness in reducing emissions is lacking. A rough estimate can be made by assuming the effectiveness to be equivalent to water spray control of dusting at heavy construction sites. Dust emission reductions of 50% have been estimated for that source when twice daily watering is performed with complete coverage of the working areas. (6-60)

Ore crushing and conveying operations usually employ fabric filters to control particulate emissions. No quantitative data on their effectiveness related to bauxite are available, but in general fabric filters are standard particulate collection devices. An overall efficiency of better than 99% is considered reasonable.

Particulate emissions from bauxite grinding are controlled at a few plants by low efficiency wet scrubbers. They have not been particularly effective, but use of alternative devices is not well documented. The reference document lists three types of wet scrubbers as possible control devices, with collection efficiencies ranging from 70 to 83% for particulates (include particulate fluorides).(6-59) An electrostatic precipitator is also listed with an associated efficiency of 98%.

Solid waste ponds could represent a significant source of windblown dust emissions due to the fine particle size of the red mud and the relatively large surface areas of the ponds. The magnitude of the source is probably small, however, since the red mud is disposed to the pond in slurry form. Furthermore, the alumina plants are located in areas with abundant precipitation, thus natural wetting of waste pond surfaces would tend to reduce the potential for dusting.

The calcination of alumina represents a major potential emission source. The airborne particulates generated in this process are essentially pure alumina, thus kiln emissions are well controlled in order to recover as much of the valuable product as possible. In general, multiple stage air cleaning is accomplished through the use of multi-cyclones followed by electrostatic precipitators or fabric filters. Collection efficiencies of 98% are reported for electrostatic precipitators. Fabric filters should be even more efficient. Although specific data were not reported for fabric filters, efficiencies of better than 99% would be expected.

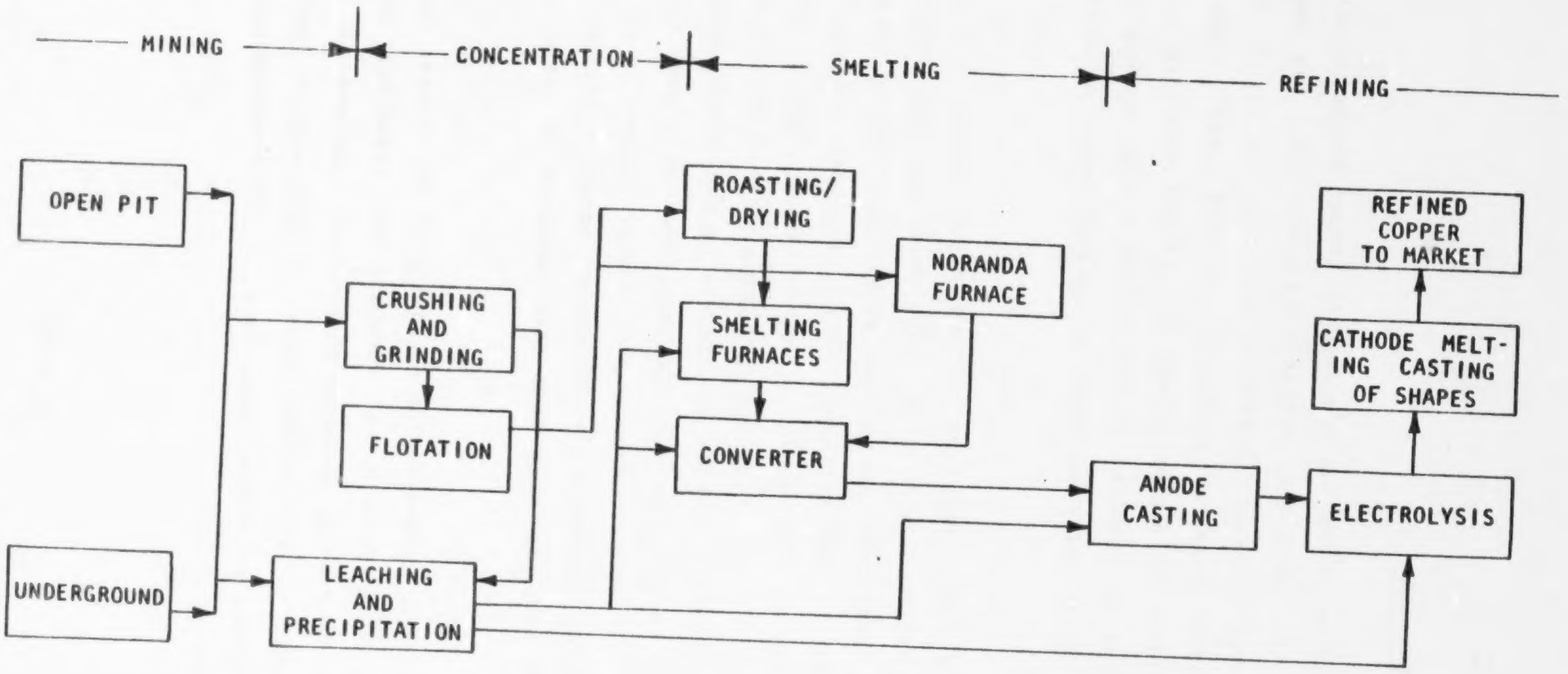
## The Copper Industry

### Industry Description

The United States is the world's leading copper producing nation. The principal copper producing states, Arizona, Utah, New Mexico, Montana, Nevada and Michigan, accounted for 62, 13, 11, 6, and 3 percent of the total domestic production in 1977.(6-61) Open pit mines are the source of approximately 90% of the mine ore output, whereas the balance is supplied by underground mining methods.(6-62) Most copper is domestically consumed as refined metal by wire and brass mills.(6-61)

The various steps required in the major copper production processes are shown in Figure 6.16. The principal four stages required for the production of refined copper are mining, ore concentration, smelting, and refining. Mining involves ore extraction and transportation of the ore to a concentrating plant. Ore concentrating consists of crushing, grinding, classification, and physical and/or chemical methods for increasing the copper content of the smelter feed.(6-63) Smelting is undertaken at a smelter plant and transforms the ore concentrate to blister copper, which is a material containing approximately 99 percent copper. Blister copper is then refined and generally cast into wirebars or other shapes. (6-62)

Primary refining refers to the upgrading of the blister copper by melting in an anode furnace and removing the principal impurity, oxygen. Secondary refining utilizes electrolytic methods for further product purification. The refined copper is then sent to fabrication mills for conversion to sheets, rods, wire, or other semi-manufactured materials.(6-62)


MINING
CONCENTRATION
SMELTING
REFINING
OPEN PIT
UNDERGROUND
CRUSHING AND GRINDING
FLOTATION
LEACHING AND PRECIPITATION
ROASTING/ DRYING
SMELTING FURNACES
CONVERTER
NORANDA FURNACE
ANODE CASTING
ELECTROLYSIS
CATHODE MELTING CASTING OF SHAPES
REFINED COPPER TO MARKET

COPPER PRODUCTION PROCESS

DAMES & MOORE

FIGURE 6.16

In 1977 the United States mined an estimated 1,351,700 metric tons, primary refined an estimated 1,451,500 metric tons, and secondary refined an estimated 408,200 metric tons of copper.

This section reviews technologies that reduce routine airborne radionuclide emissions through the production of blister copper. It is assumed that blister copper will contain negligible radionuclide concentrations and that discussion of controls during further refining will not be necessary.

## Ore Geology and Radionuclide Content

Only fifteen from amongst the approximately 150 copper-bearing minerals are of major economic importance.(6-64) These minerals can be classified as sulfides (chalcopycite, chalcocite, bornite, covellite, enargite, and tetrahedrite-tennantite), oxidation products (atacamite, malachite, chrysocolla, cuprite, tenocite, brochantite, and antlerite), and native copper.(6-64) The minerals and their chemical formulas are listed in Table 6-38. Most copper ore deposits can be classified as belonging to one of the following five types of occurrences: porphyry, vein, and replacement deposits; stratabound deposits in sedimentary rocks; massive sulfide deposits in volcanic rocks; magmatic segregates of nickel-copper ores; and native copper ores.

Porphyry, vein, and replacement deposits account for almost two-thirds of the worlds copper resources.(6-61) Porphyritic copper deposits are the major source of copper mined in the United States. (6-65) They are large, relatively low-grade occurrences of disseminated copper minerals genetically associated with felsic igneous intrusions.(6-61) Most porphyry copper deposits contain overall copper contents ranging between 0.5 and 1.0 percent, with some of the deposits being economically mined only because of weathering induced enrichment.(6-65) The Ajo, Bisbee, Globe-Miami, Morenci, Ray, and

## TABLE 6-38

### Copper Ore Minerals of Economic Interest (6-64)

| Group/Mineral | Chemical Formula |
|---|---|
| Sulfides | |
| Chalcopyrite | $C_uFeS_2$ |
| Chalcocite | $Cu_2S$ |
| Bornite | $Cu_5FeS_4$ |
| Covellite | $CuS$ |
| Enargite | $Cu_2AsS$ |
| Tetrahedrite-Tennanite | $Cu_2(Sb,As)S$ |
| Oxides | |
| Atacamite | $Cu_2(OH)_3Cl$ |
| Malachite | $Cu_2(OH)_2(CO_3)$ |
| Chrysocolla | $CuSiO_3.2H_2O$ |
| Cuprite | $Cu_2O$ |
| Tenorite | $CuO$ |
| Brochantite | $Cu_4(SO_4)(OH)_6$ |
| Antlerite | $Cu_3(SO_4)(OH)_4$ |
| Native Copper | $Cu$ |

Silver Bell deposits of Arizona, Santa Rita deposit of New Mexico; and Bingham deposit of Utah are examples of porphyritic copper deposits. (6-65) Vein and replacement type deposits are generally associated with porphyritic intrusions as locallized concentrations in favorable host rock.(6-61) Parts of the Morenci and Bingham deposits belong to this class of occurrence.(6-64) Almost all of the Butler, Montana copper deposit consists of vein ore.(6-64)

Approximately 25% of the worlds copper reserves occur as strata-bound deposits in sedimentary rock.(6-61) The host rock is most often black shales.(6-63) Deposits occur in red bed facies and associated sandstones as well and occasionally in carbonate rocks. (6-64) The White Pine deposit of Michigan is a black shale copper deposit. Examples of red bed and associated sandstone copper deposits are found on the Colorado Plateau in eastern Utah, western Colorado, northern Arizona, and northwestern New Mexico. Native copper ores are typified by the Keewenaw Pennisula, Michigan deposits in which native copper is associated with basaltic lava.(6-61)

Data concerning the levels of radioactivity associated with copper ores consist principally of ore radionuclide analyses, mine pumpout water analyses, and radon daughter working level measurements in undergound mine atmosphere. Much of these data are summarized by U.S. EPA (1978).(6-66) A positive correlation between the rock uranium concentration and the occurrence of porphyry copper has been found for the Copper Cities and Castle Dome open pit porphyry copper mines in Arizona. Uranium concentrations of the ore body at the Copper Cities mine are factors of 11-38 larger than those for non-mineralized igneous rocks of the same composition in the region. The primary ore zone exhibits an average $U_3O_8$ concentration of 100 ppm (57.5 pCi/g), whereas the non-mineralized igneous rocks of the same composition in the region have an average $U_3O_8$ concentration of approximately 4 ppm (2.3 pCi/g). The Castle Dome ore body has an average $U_3O_8$ concentration of 20 ppm (11.5 pCi/g). From this data it is apparent that some porphyry copper deposits contain commercially extractable concentrations of uranium. A 143,000 lb. per year $U_3O_8$ extraction circuit is in fact being constructed for the copper leaching operation at the Bingham porphyry copper mine. Ten uranium ore analyses representing four ore types at the Bingham mine are shown in Table 6-39.(6-67) The uranium concentrations range from 0.15-8.0 ppm (0.10-5.4 pCi/g) and are substantially higher in the granitic rocks than in the quartzites and carbonates.(6-67) Table 6-40 contains the results of uranium assays of mineralized and non-mineralized intrusions of another study of porphyry copper deposits. The average uranium concentrations of the mineralized intrusions are found to be less, however, than the average uranium content of regional igneous rocks of 4 ppm.(2.3 pCi/g).(6-66)

Tables 6-41 and 6-42 contain pumpout water analyses and underground mine atmosphere radon daughter working level measurements for copper mines of several deposit types.(6-66) The relationship of these data to the radionuclide concentrations of the ore body are unclear. The physical and chemical characteristics (such as pH and complexing ion concentrations) of the waters are not known. The radon daughter concentrations of the mine atmospheres are dependent upon the ore radium concentrations, emanation properties of the ore, presence of mine water, and the mine ventilation rates. Radon daughter concentration levels have posed health hazards to mining personnel in several underground copper mines.(6-66)

From the review data it can be concluded that some copper deposits have the potential for enriched radionuclide concentrations relative to local, non-mineralized rocks.

## Ore Processing Description

The blister copper production process starting from mining is described in detail in this section. A generalized ore processing

## TABLE 6-39

### The Uranium Concentrations of Copper Ore
### From the Kennecott Bingham, Utah Mine
### Ref. (6-67)

| Sample | Rock Type | U in ppm |
|---|---|---|
| 1960 Magna Head | Composite | 4.9 + 1.0 |
| Biotite Concentrate | Granite Porphyry, GM-101 | 6.8 ± 1.0 |
| GM-108 | Granite | 8.0 ± 2.0 |
| GM-106 | Granite | 4.2 ± 0.8 |
| GM-129 | Granite Porphyry | 5.3 ± 1.5 |
| GM-101 | Granite Porphyry | 2.9 ± 1.0 |
| GM-103 | Quartzite | 1.8 ± 0.6 |
| GM-113 | Quartzite | 2.2 ± 0.6 |
| GM-120 | Meta Limestone | 2.2 ± 0.6 |
| GM-115 | Meta Limestone | 0.15 ± 0.12 |

## TABLE 6-40

### Average Abundances of Uranium in Porphyry Copper Intrusions and Barren Intrusions of Similar Composition*

Ref. (6-66)

| Location | Occurrence | Samples | Average ppm Uranium | Range ppm Uranium |
|---|---|---|---|---|
| New Cornelia Mine | Mineralized Stock | 17 | 1.25 | 2.1-0.4 |
| New Cornelia Pluton | Barren Intrusion | 12 | 0.68 | 1.3-0.2 |
| Mineral Park Mine | Mineralized Stock | 25 | 0.79 | 3.5-0.1 |
| Gross Peak-Martin Ridge | Mineralized Stock | 13 | 0.46 | 0.9-0.2 |
| Turquoise Mountain | Mineralized Stock | 23 | 1.27 | 2.4-0.6 |
| Morenci Pit | Mineralized Stock | 23 | 0.71 | 2.5-0.2 |
| Morenci Stock | Barren Stock | — | ---- | ---- |
| Santa Rita Deposit | Mineralized Stock | 32 | 1.24 | 4.7-0.3 |
| Fierro-Hanover | Barren Stock | 6 | 0.52 | 0.3-0.8 |

* Uranium spectrometrically analyzed. All analyses are from whole-rock samples except for soil samples of uranium at New Cornelia Pluton, Gross Peak-Martin Ridge, and Turquoise Mountain.

# TABLE 6-41

### Radon-Daughter Sample Concentrations In Underground Copper Mines*
Ref. (6-66)

| Mine | Location | No. of Samples | Average Radon Daughter Conc. (WL) | Range of Radon Daughter Conc. (WL) | Approx. Avg. Existing Ventilation (CFM) |
|---|---|---|---|---|---|
| Indian Creek* | Missouri | 8 | 0.023 | .004-0.115 | Not Available |
| Virurnum** | Missouri | 8 | 0.065 | .002-0.117 | Not Available |
| Eagle Mine*** | Colorado | 10 | Less than .1 | Not Available | Not Available |
| 85 Mine | New Mexico | 10 | 0.180 | 0.060-0.280 | 10,000 |
| White Pine | Michigan | 11 | 0.030 | 0.01-0.04 | 330,000 |
| Calloway | Tennessee | 11 | Negligible | Negligible | Not Available |
| Copper Queen | Arizona | 42 | 0.330 | 0.02-1.7 | 5,000 |

---

* Data provided by U.S. Dept. of the Interior, Mining Enforcement and Safety Administration, Denver, CO.

** Lead, Zinc Copper

*** Lead, Zinc, Copper, Gold, Silver

## TABLE 6-42

### Radiological Analysis of Copper Mine Pumpout Water
Ref. (6-66)

| Mine | Source | Ra-226 (pCi/l) | Total Uranium (mg/l) |
|---|---|---|---|
| White Pine (Michigan) | Mine Water Discharge #3 | 13.6 | <0.1 |
| | Mine Water Discharge #2 | 4.2 | <0.1 |
| | Mine Water Discharge #3 | 27.3 | <0.1 |
| Butte (Montana) | Kelley Operation Mine Water | 4.8 | <0.2 |
| | Berkley Pit Mine Water | 1.5 | <0.1 |
| | Continental East Mine Water | 3.0 | <0.1 |
| | Input to Emergency Pond | 1.7 | <0.1 |
| Old Reliable (Arizona) | 300' Level Mine Drainage | 2.6 | <0.1 |
| Bagdad (Arizona) | East Pit Mine Water | 1.6 | <0.1 |
| | West Pit Mine Water | 12.7 | 0.25 |

scheme is shown in Figure 6-.6. The production of blister copper in general consists of three stages: mining, concentrating, and smelting. Each of these stages is discussed separately below.

### Mining

Mining comprises the initial stage of copper production from ore. It has been estimated that approximately 98 percent of the domestic mined copper originates from ore mined primarily for its copper content.(6-62) The remainder is recovered from complex or mixed base metal ores.(6-62) Open pit mines accounted for 90 percent of mine output in 1977, whereas the balance of ore was supplied by underground mining methods.(6-62) The open pit ore extraction cycle consists of drilling, blasting, loading, and ore transport. The two most prevelant underground mining techniques utilized are block caving and sublevel caving.(6-62) In situ leaching is a combined underground mining/concentrating technique. A leaching solution is contacted with ore in shattered and broken rock zones or in a porous formation to dissolve the copper. The pregnant solution is then removed.

### Concentrating

Ore concentrating consists of crushing, grinding, classification, and physical and/or chemical methods for increasing the copper content of the smelter feed. Crushing and grinding are multi-stage processes. Primary crushing is typically undertaken at the mine while grinding occurs at the smelter. The final ground ore contains a mixture of particles between 65 and 200 mesh.(6-63)

The two major techniques for increasing the copper content of the smelter feed are flotation and leaching/precipitation. Flotation is most commonly utilized for sulfide ores (the principal ore type currently processed) for separating the ore minerals from the gangue. Air is introduced into the ore slurry from the final grinding stage along with chemical agents that produce a froth of air bubbles which rise to the top of the flotation cell. The copper sulfide minerals attach to the froth bubbles and float whereas the gangue sinks to the bottom and is discarded as tailings. The separated ore concentrate is then sent through further flotation steps for additional impurity separation.

Copper dissolution via a dilute sulfuric acid leach is employed for oxide ores not amenable to flotation.(6-62) Four presently employed leaching techniques are dump leaching, heap leaching, vat leaching, and in-situ leaching.(6-62) Copper is leached from low-grade waste materials from open pit deposits by dump leaching. The leaching cycle is on the order of several years. Heap leaching has a leaching cycle on the order of months and is used for copper dissolution from oxide ore piled on a prepared surface. Copper is extracted from crushed and sized oxide ore by vat leaching. The leaching cycle is on the order of days. In-situ leaching has been previously discussed. A fifth leaching technique of future potential is thin layer leaching.(6-68) This technique entails curing piles of crushed ore treated with leach solution and spreading the ore in layers of three feet or less on prepared pads for subsequent leaching (Ref 4).

Copper is also recovered from solution by chemical precipitation on scrap iron or by a direct electrowinning process (Ref 2). The precipitated copper may be initially processed at a smelter or directly at a refinery.

The treatment of mixed sulfide-oxide ores depends upon the proportions of the two mineral types.(6-62) Ores in which sulfide minerals predominate utilize flotation employing reagents that favor oxide mineral flotation. Combinations of leaching and flotation are utilized for ores containing approximately equal quantities of sulfide and oxide minerals.

## Smelting

Smelting is here defined as all processes necessary for the transformation of copper concentrate to blister copper and encompasses drying, roasting, furnace smelting, and converting. Part of Table 6-43 lists the major portions of the smelting process utilized at 13 of the 16 operating domestic smelters. It should be noted that some of the smelters reviewed in Table 6-43 reflect either recent changes or will undergo change in the near future (i.e., Anaconda, Montana and McGill, Nevada smelters). The copper industry is presently in a transition period, especially in regard to changing process design for reducing sulfur dioxide ($SO_2$) emissions to the environment and increasing energy usage efficiency.

Copper concentrate is frequently roasted prior to being fed to a smelting furnace. Roasting reduces the concentrate sulfur content and oxidizes some of iron by heating so that subsequent furnace smelting is more efficient. It also reduces the concentrate moisture content, volatilizes some of the arsenic and antimony, and preheats the concentrate just prior to furnace feeding. The final product of roasting is referred to as "calcined feed".

Conventional roasting is accomplished by either multiple-hearth or fluidization processes. A cross section through a multiple hearth roaster is shown in Figure 6.17.(6-69) The roaster is a cylindrically shaped vessel fitted with a series of round horizontal trays or hearths. Ore concentrate is introduced at the top of the vessel and is raked across each hearth in turn until it is discharged at the bottom of the roaster.(6-63) Heat may be supplied by burners underneath each hearth although firing beneath the lowest hearths are most common. Air is introduced if necessary to maintain the high internal temperature. Multi-hearth roasters can roast 125-650 metric tons of concentrate per day.(6-63) Multi-hearth roasters are presently employed at four domestic smelters: Asarco-Hayden, Arizona, Douglas,

## TABLE 6-43

### Particulate Controls Employed At Some Domestic Smelters[a]

| Smelter | Dryer Offgas Treatment | Roaster Offgas Treatment | Smelter Furnace Offgas Treatment | Converter Offgas Treatment | Operating Conditions |
|---|---|---|---|---|---|
| ASARCO, Inc.<br>El Paso, Texas<br>1000 TPD concentrate smelting capacity, 4 multi-hearth roasters, 1 reverberatory furnace, 2 operating Pierce-Smith converters. | -- | As of 1976, the roaster gases pass through a settling flue & join the reverberatory gases prior to a spray chamber, an ESP & stack release. Future plans entail treating the roaster offgas together with offgas from smelter & sintering machine in a new sulfuric acid plant. | Furnace offgas passes through waste heat boilers and is then combined with the roaster offgas | Converter offgases, cooled in waste heat boilers & a spray chamber, are treated by an ESP followed by a double-contact acid plant gas cleaning system. | Roaster offgas: 95,000-110,000 SCFM, 330°F.<br>Furnace offgas (after the waste heat boilers): 60,000-80,000 SCFM, 650°F.<br>Combined gas streams (after ESP): 190,000-220,000 SCFM, 250°F. |
| ASARCO, Inc.<br>Hayden, AZ<br>2000 TPD concentrate smelting capacity, 12 multiple-hearth roasters (6-8 normally on line at a time), 2 reverberatory furnaces 5 Pierce-Smith convertors (3 in operation at a time). | No Dryers | Settling chamber followed by 28 unit ESP and stack discharge. | Cooled & humidified furnace offgases are combined with roaster offgases in the settling chamber. | Cyclone, spray chamber, & ESP prior to entrance into the acid plant gas cleaning system. | Roaster offgas (prior to the settling chamber): 140,000-150,000 SCFM, 150°F.<br>Furnace offgas (after spray chamber): 150,000-180,000 SCFM, 300°F.<br>Combined roaster and furnace offgas (after the ESP) 270°F. |

TABLE 6-43 (cont'd)

| Smelter | Dryer Offgas Treatment | Roaster Offgas Treatment | Smelter Furnace Offgas Treatment | Converter Offgas Treatment | Operating Conditions |
|---|---|---|---|---|---|
| | | | | | Converter offgas (after ESP): 100,000 SCFM. |
| ASARCO, Inc.<br>Tacoma, WA<br>10 multiple-hearth roasters (4-6 are routinely on line at a time), 1 on line reverberatory furnace, 2 on-line converters. | No Dryers | Roaster offgases pass through a spray chamber & are then treated by a dry pipe type ESP followed by parallel plate type ESPs prior to stack release. | Furnace offgas is cooled in waste heat boilers & is combined with roaster offgases in a spray chamber prior to ESP treatment. | Converter offgases are subjected to a comprehensive gas conditions and cleanup sequence including ESPs & scrubbers prior to feeding a sulfuric acid plant & DMA scrubbing system. | Total roaster offgas: 95,000-110,000 SCFM, 330°F.<br>Reverberatory furnace offgas 70,000-100,000 SCFM, 600°F. |
| Anaconda Co. [b]<br>Anaconda, Montana<br>2000 TPD concentrate smelting capacity, 4 reverberatory furnaces, 4 on-line Pierce-Smith converters. | --- | --- | Furnace offgases are cooled in either a waste heat boiler or water quenched cooling chamber pass through an ESP prior to stack releases. | A portion of the converter offgases are combined with with smelter furnace off-gases prior to passage through an ESP. The remainder of the gases are directed through a double contact sulfuric acid plant gas cleaning system. | --- |
| Inspiration Consolidated Copper Co.<br>Inspiration, AZ<br>1500 TPD combined | Dust cyclone and baghouse filter prior to release. | No Roasters | Cooled furnace offgas is treated by a cyclone, ESP, and then is released | Converter offgases are combined with furnace offgas following cooling | Furnace offgas (Following cooler): 975°F. |

TABLE 6-43 (cont'd)

| Smelter | Dryer Offgas Treatment | Roaster Offgas Treatment | Smelter Furnace Offgas Treatment | Converter Offgas Treatment | Operating Conditions |
|---|---|---|---|---|---|
| dry concentrate and flux smelting capacity, 1 dryer, 1 electric smelter, 5 Hoboken converters. | | | to the acid plant gas cleaning system. | and passage through a cyclone and ESP. | Converter offgas (following cooler): 975°F.<br>Combined furnace & converter offgas: 45,000-129,000 SCFM, 97,000 SCFM Avg., 500-575°F at the acid plant entrance. |
| Kennecott Copper Corp. Hayden, AZ 1128 TPD concentrate, smelting capacity, 1 fluidization roaster, 1 reverberatory furnace, 3 Pierce-Smith converters) | No Dryers | Roaster offgas is treated in order, by cyclones, a gravity precipitator & a wet scrubber prior to release to an acid plant gas cleaning system | Furnace offgas is passed through an ESP prior to stack release | Converter offgases are passed through an ESP and wet scrubber prior to entering the gas cleaning system of an acid plant | Roaster offgas: 125,000 SCFM<br>Furnace offgas: 100,000 SCFM<br>Converter offgas: 100,000 SCFM |
| Kennecott Copper Corp.[c] Hurley, NM 850 TPD green concentrate smelting capacity, 1 operating reverberatory furnace (2 total), 3 converters. | --- | No Roasters | Furnace offgas, cooled in a waste heat boiler, is treated by an ESP prior to stack release. | Converter offgases are processed by a double-contact acid plant | Furnace offgas (Following ESP): 240,000-270,000 SCFM, 425°F. |

## TABLE 6-43 (cont'd)

| Smelter | Dryer Offgas Treatment | Roaster Offgas Treatment | Smelter Furnace Offgas Treatment | Converter Offgas Treatment | Operating Conditions |
|---|---|---|---|---|---|
| Kennecott Copper Corp. McGill, NV Prior to 1976: 800-1000 TPD concentrate smelting capactiy, 2 reverberatory furnaces, 3 converters. | --- | --- | Furnace offgases are cooled in a waste heat boiler and treated by an ESP prior to stack release. | Emissions collected from auxilliary hooding in the converter area are vented to the reverberatory furnace gas system prior to stack release.[d] | Furnaces offgas prior to 1976 (Following ESP): 200,000-250,000 SCFM, 500°F. |
| Magma Copper Co. San Manuel, AZ 3150 TPD concentrate smelting capacity, 3 greenfeed reverberatory furnaces, 6 Pierce-Smith converters) | --- | No Roasters | Offgases from the 3 furnaces are cooling waste heat boilers, treated by ESPs, & released through stacks. | Converter offgases are passed through an ESP & a wet scrubber prior to release to an acid plant gas cleaning system | Furnace offgas: 4.31 x $10^8$ SCF/day<br>Converter offgas: 2.81 x $10^8$ SCF/day |
| Phelps Dodge Corp. New Cornelia Smelter Ajo, AZ 700 TPD concentrate smelting capacity, 1 reverberatory furnace, 3 converters | --- | No Roasters | Furnace offgas is cooled in a waste heat boiler and passed through an ESP prior to entrance into the initial gas cleaning system of a DMA scrubbing plant.[e] | Converter offgases are cleaned by an ESP prior to entrance into an acid plant gas cleaning system | Furnace offgas (after the ESP & prior to further cleaning) 45,000-55,000 SCFM, 450°F.<br>Converter offgas (after ESP). 60,000-78,000 |
| Phelps Dodge Corp Douglas, AZ 2800 TPD concentrate smelting capacity, | No Dryers | Roaster offgases are treated in a common ESP prior to stack release. | Furnace offgases are cooled in waste heat boilers prior to passage through | Converter offgases are treated by ESPs prior to stack release. | Total roaster offgas: (after ESP). 260,000-290,000 SCFM, 380°F. |

TABLE 6-43 (cont'd)

| Smelter | Dryer Offgas Treatment | Roaster Offgas Treatment | Smelter Furnace Offgas Treatment | Converter Offgas Treatment | Operating Conditions |
|---|---|---|---|---|---|
| 24 multi-hearth roasters (18 normally in operation at a time), 3 reverberatory furnaces, 5 Pierce-Smith converters (4 normally in operation at at time). | | Ground smoke caused by roaster leakage is collected & sent through a baghouse filter prior to channeling into the roaster offgas system. | an ESP & stack release (the same stack as the roaster gases are released from). | | Total reverberatory furnace offgas (after ESP): 145,000-156,000 SCFM, 450°F.<br>Total converter offgas (after ESP): 210,000-265,000 SCFM, 350°F. |
| **Phelps Dodge Corp.**<br>Morenci, AZ<br>2000 TPD concentrate smelting capacity, 1 fluidization roaster<br>5 reverberatory furnaces (3 of which are green-feed) 9 Pierce-Smith Converters (7 operating under normal conditions). | --- | Roaster offgas is treated by cyclones prior to release to the gas clean-system of a single-contact sulfuric acid plant. | Furnace offgases cooled in waste-heat boilers, are passed through ESPs prior to stack release. | Converter offgases are passed through coolers, ESPs, and then the gas cleaning cleaning system of an acid plant. | Roaster offgas (after the gas cleaning system & prior to the acid plant). 38,000-42,000 SCFM<br>Reverberatory furnace offgases (after ESP): 340,000-500,000 SCFM, 450°F.<br>Converter offgases: 180,000-237,000 SCFM |
| White Pine **Copper Co.**<br>White Pine, Mich.<br>2 reverberatory | --- | No Roasters | Furnace offgases are passed through waste heat boilers to a common flue | Converter offgas is vented directly to a stack without special particulate removal treatment. | Combined furnace offgas. 160,000-185,000 SCFM, 500°F. |

TABLE 6-43 (cont'd)

| Smelter | Dryer Offgas Treatment | Roaster Offgas Treatment | Smelter Furnace Offgas Treatment | Converter Offgas Treatment | Operating Conditions |
|---|---|---|---|---|---|
| furnaces, 2 Pierce-Smith converters (1 on line at a time). | | | and are cleaned in an ESP prior to stack release. | | Converter offgas 99,000<142,000. SCFM, 550°F (Intermittent flow). |

---

a. Source: Ref. 6-69, 6-70, 6-71.
b. Was in the final stages of changing to fluidization roasting and an electric furnace process as Ref. 6-14.
c. Improved smelting process based upon converter smelting with oxygen enriched blast air and supplemental heating planned as of 1974. This will essentially eliminate the reverberatory furnace process (Ref. 6-14).
d. Planned for 1976.
e. DMA (dimethylaniline) plant was not operational (Ref. 6-13).

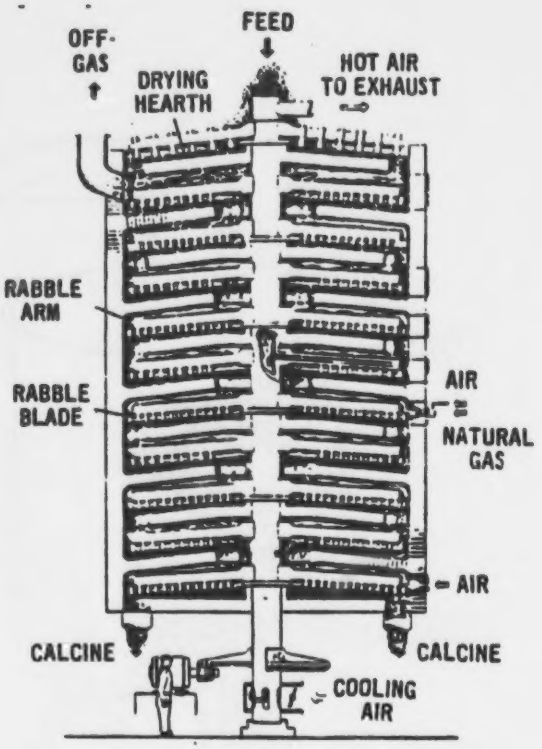
Arizona; Tacoma, Washington; and El Paso, Texas. There presently appears to be a general trend away from the use of multi-hearth roasters.(6-63)

Figure 6.18 shows the internal structure of a fluidization roaster. (6-69) Hot gas is blown up through the introduced ore concentrate at a sufficient velocity to keep it in constant suspension.(6-63) The ore concentrate is continuously fed and overflows the vessel. Fluidization roasters are presently utilized at four domestic smelters, including the Kennecott-Hayden, Arizona and Phelps-Dodge - Morenci, Arizona smelters.

Roasting is generally not as widely practiced today as it was in the past. Recently this trend has been reversed due principally to the advantages of roasting for minimizing $SO_2$ emissions and being conducive to sulfur recovery from the furnace smelting process.(6-72)

Copper concentrate that is not processed by roasting passes through a dryer prior to being fed to the smelter furnace. The sole function of drying is moisture removal to reduce the chance of smelter furnace eruptions or explosions.(6-72) Dried concentrate is referred to as "green feed". Drying is accomplished in multi-hearth roasters operated at lower temperatures or in special dryers. Drying may be more conveniently undertaken at the concentrator plant than at the smelter. A smelter having a drying unit is in use at Inspiration, Arizona.

Furnace smelting removes much of the iron and some other undesirable impurities from a roasted or dried ore concentrate. A molten mixture is produced that can be processed efficiently by a converter. Conventional furnace smelting in the United States is accomplished in reverberatory, electric, and flash smelting units.

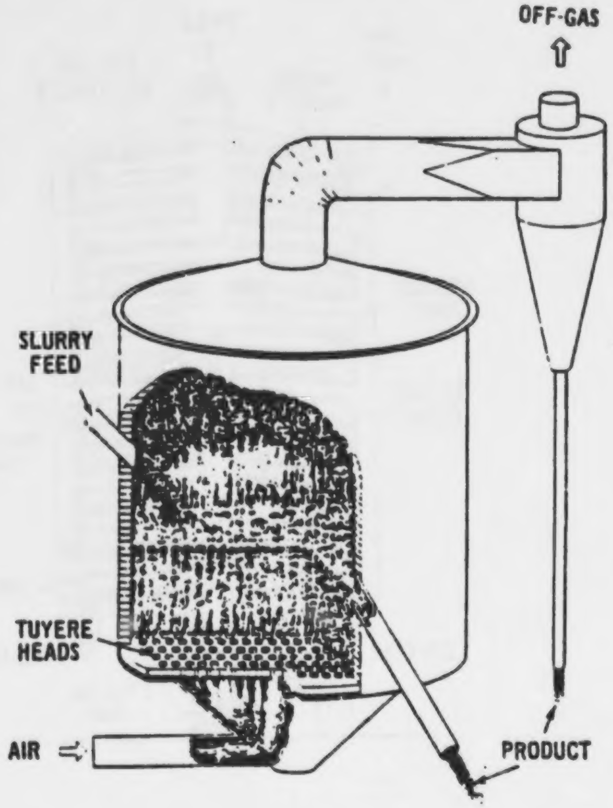

OFF-GAS
FEED
DRYING HEARTH
HOT AIR TO EXHAUST
RABBLE ARM
RABBLE BLADE
AIR
NATURAL GAS
AIR
CALCINE
CALCINE
COOLING AIR

MULTI -HEARTH ROASTER

Source: Reference 6-69

DAMES & MOORE

FIGURE 6.17


OFF-GAS
SLURRY FEED
TUYERE HEADS
AIR
PRODUCT

FLUIDIZATION - BED ROASTER

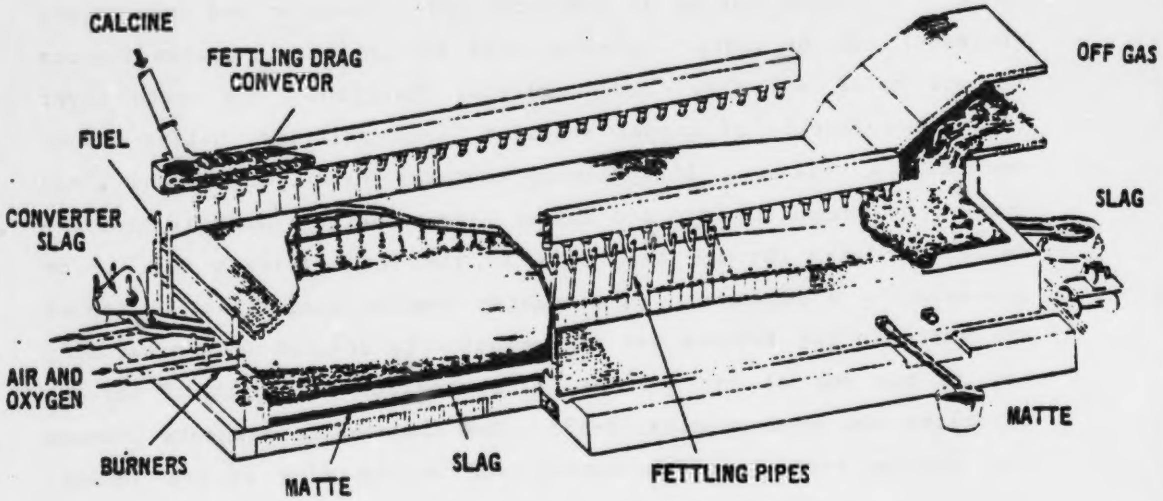
Source: Reference 6-69

DAMES & MOORE

FIGURE 6.18

Reverberatory furnace smelting is the oldest and most widely used process.(6-63) A typical reverberatory furnace is depicted in Figure 6.19. The furnace is a large, arch-roofed, horizontal chamber. Fluxes normally added to the furnace in addition to the concentrate include quartz sand and limestone. Materials for reprocessing, such as flue dust and slag are also added. "Direct smelting ore" is added at times. The flame, which is introduced at one end of the chamber, "reverberates" off the roof and strikes the charge from above. A complex series of reactions takes place as the temperature increases and the charge separates into two immiscible molten liquids (copper matte and slag) and a gaseous fraction. The matte layer consists primarily of copper sulfides, iron sulfides, native copper and residual sulfur. It typically contains 40-45 percent and 25-30 percent by weight of iron and sulfur respectively. Matte is periodically withdrawn through tap holes in the lower furnace wall to be processed by a converter. The lighter density slag floats on top of the matte in the furnace and is periodically drained from a skimming bay at one end of the furnace. Slag consists primarily of ferrous silicates and some alumina.(6-63) The lithophilic elements uranium and thorium were found to concentrate in the slag of the Tacoma, Washington reverberatory furnace during a trace element partitioning study.(6-73) The gaseous fraction consists of sulfur dioxide and volatiles which mix with the combustion off-gases. Reverberatory furnaces are utilized at 11 of the 16 smelters in the United States. Some reverberatory furnaces are large enough to accept as much as 1800 metric tons of material per charge.(6-63)

Electric smelting utilizes electricity to supply heat for melting. Figure 6.20 shows a cross section through an electric smelting furnace.(6-74) Matte, slag, and gaseous layers are produced as in the case of reverberatory furnace smelting. Carbon electrodes are utilized in electric smelting to conduct electric current to the slag layer and are consumed during operation. Fluxing materials are required in addition to the ore concentrate. There are three

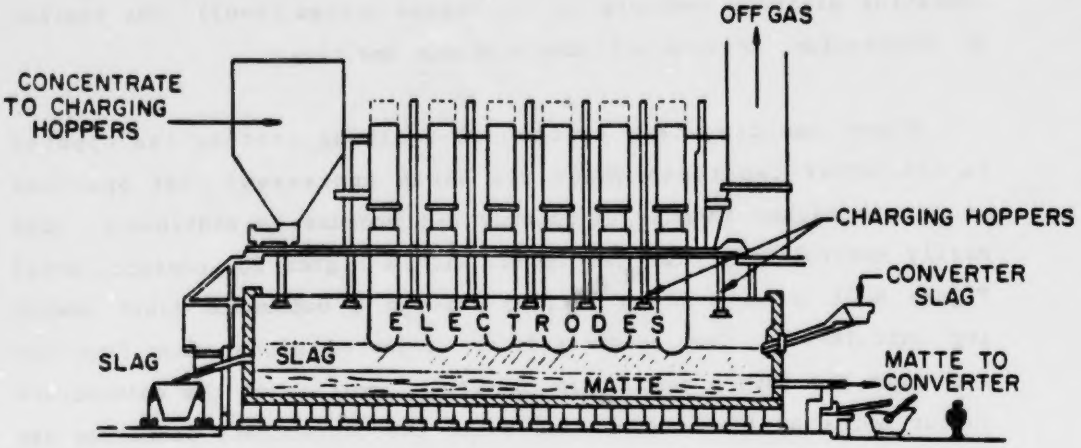

CALCINE
FETTLING DRAG CONVEYOR
FUEL
CONVERTER SLAG
AIR AND OXYGEN
BURNERS
MATTE
SLAG
FETTLING PIPES
OFF GAS
SLAG
MATTE

REVERBERATORY SMELTING FURNACE

Source: Reference 6-69

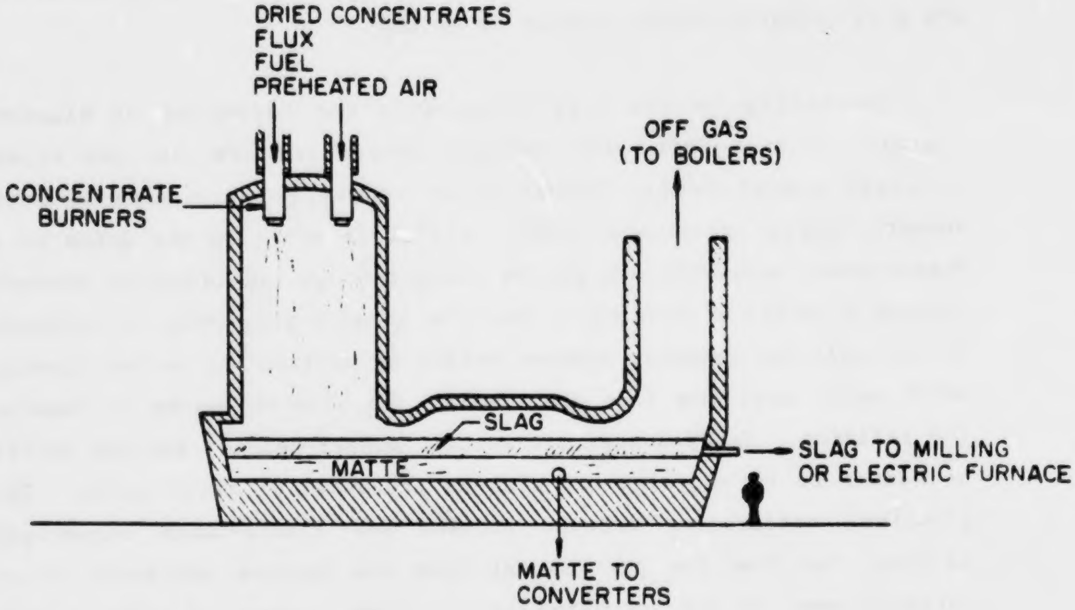
DAMES & MOORE

FIGURE 6.19


OFF GAS
CONCENTRATE TO CHARGING HOPPERS
CHARGING HOPPERS
CONVERTER SLAG
ELECTRODES
SLAG
SLAG
MATTE
MATTE TO CONVERTER

ELECTRIC SMELTING FURFACE

Source: Reference 6-74


DRIED CONCENTRATES
FLUX
FUEL
PREHEATED AIR
OFF GAS (TO BOILERS)
CONCENTRATE BURNERS
SLAG
SLAG TO MILLING OR ELECTRIC FURNACE
MATTE
MATTE TO CONVERTERS

OUTOKUMPU FLASH FURNACE

Source: Reference 6-74

DAMES & MOORE

FIGURES 6.20 & 6.21

operating electric smelters in the United States.(6-63) The smelter at Inspiration, Arizona utilizes electric smelting.

Flash smelting is a continuous smelting process (as opposed to the other two types which are batch processes) that operates at a much higher thermal efficiency and produces a continuous, more easily controllable flue gas stream with a higher $SO_2$ content.(6-63) Figure 6.21 shows a cross section through a Outokumpu flash smelting unit.(6-74) Ore concentrate is injected along with flux and preheated air into a combustion chamber. A portion of the concentrate sulfur burns by flash combustion while the concentrate particles are falling through the chamber. The smelting temperature is maintained by the combustion heat. Matte, slag, and gaseous layers are formed. The slag contains too much copper to discard and is further processed. (6-63) Only one smelter in the United States utilizes flash smelting. It utilizes an Outokumpu type unit.(6-63) Most of the remaining sulfur and iron in the matte is conventionally removed in a converter and a 99% blister copper product is formed.

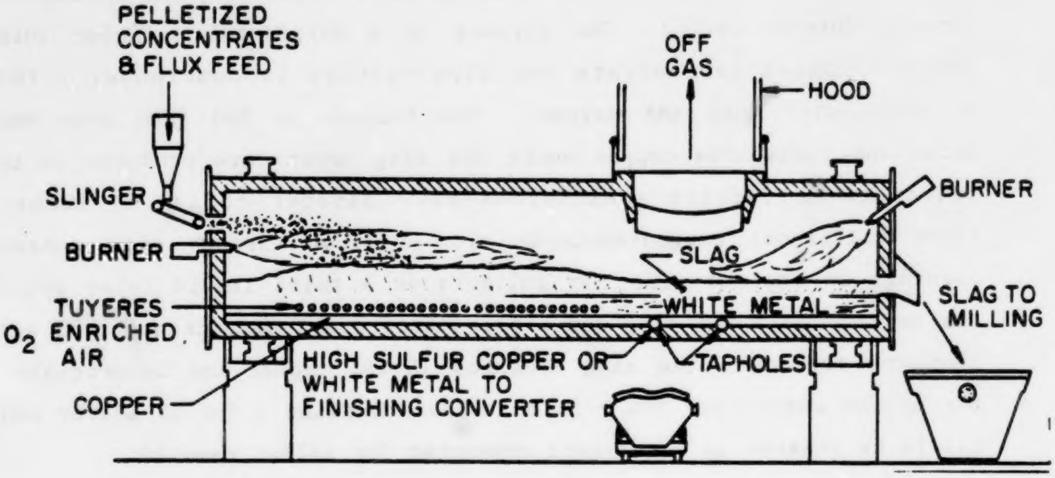
Converting is the last process in the formation of blister copper. Pierce-Smith and Hoboken converters are the two types utilized domestically. Pierce-Smith converters are used by most domestic copper producers.(6-63) A flux is added to the matte in a Pierce-Smith converter and air is blown through the resultant mixture through a series of openings. The iron forms a slag which is returned to the smelting furnace, whereas sulfur is oxidized to sulfur dioxide which exits with the flue gas.(6-63) The blister copper is removed for refining. Scrap copper and certain copper-bearing smelter spills or wastes to be recycled can also be processed with the matte. The principal differences between Hoboken and Pierce-Smith converters is that the flue for gas removal from the Hoboken converter is an integral part of the converter construction instead of being a hood mounted above it. Infiltration of uncontaminated air is minimized, local losses of sulfur dioxide from the converter mouth are reduced, and a gas with a higher and more uniform sulfur dioxide content is produced as a result of the Hoboken converter flue design. A Hoboken converter is domestically utilized at only the Inspiration, Arizona smelter.(6-63)

A Noranda process smelting installation, in which most of the roasting-smelting and converting is accomplished in a single furnace, is being implemented by Kennecott Copper Corporation at Garfield, Utah.(6-63) Figure 6.22 shows a cross section through a Noranda furnace.(6-74) The furnace is a horizontal cylinder into which a copper concentrate and flux mixture is continuously fed in along with fuel and oxygen. The furnace is fed from both end walls and immiscible copper matte and slag layers are produced as in conventional furnace smelting.(6-63) Blister copper is formed after additional oxygen-enriched air is blown through side-mounted openings in the furnace. It collects in a third liquid layer below the matte. Both the slag and copper matte are intermittently removed from the furnace. The slag contains 10-12% copper and is processed for copper recovery. The blister copper contains 1.5-2.0% sulfur and has to be treated in a standard converter for sulfur removal.

## Airborne Radionuclide or Particulate Emissions

Particulates associated with radionuclides may be released in ore and process dust, however little data exists concerning particulate radionuclide releases during blister copper production. A discussion of general dust emission sources during production is presented. Radionuclide-specific data is presented where available.

Drilling, blasting, loading, and ore transport are sources of dust release from mining. A fugitive dust emission of 110 grams per metric ton of ore mined has been reported as the average for several types of non-ferrous metal mining.(6-63) The composition of the dust is a function of the ore composition. There is a large particle size variation in the dust emissions.


PELLETIZED CONCENTRATES & FLUX FEED
OFF GAS
HOOD
SLINGER
BURNER
BURNER
SLAG
TUYERES
WHITE METAL
SLAG TO MILLING
$O_2$ ENRICHED AIR
HIGH SULFUR COPPER OR WHITE METAL TO FINISHING CONVERTER
TAPHOLES
COPPER

NORANDA FURNACE

Source: Reference 6-74

**DAMES & MOORE**

FIGURE 6.22

The handling and milling of dry ore during the concentration stage of blister copper production are sources of dust emissions. A total dust emission of 1 kilogram per metric ton of ore processed has been reported from these sources.(6-63) Ore leaching and flotation are wet processes that should result in negligible particulate releases.

Drying, roasting, furnace smelting, and conversion are sources of dust during the smelting stage of blister copper production. Fugitive dust from drying is of the same composition as the input copper concentrate, since dryer operating temperatures are below those for volatilization of any of the major constituents. A dust emission of 0.05% of the feed has been reported for a multiple hearth roaster used for drying at a foreign smelter.(6-63) No data are known for domestic dryers.

Dust emitted from roasters consists of materials of low volatility (i.e., copper and iron) and fumes. The fumes are composed of materials of high volatility that leave the roaster in vapor form and later condense at lower temperatures. Arsenic and antimony are among the high volatility elements found in roaster fumes. Multiple hearth roasters generate approximately 75 kilograms of particulates per metric ton of copper produced.(6-63) Approximately fifteen percent of the particulates have diameters smaller than 10 microns. (6-63) Significant fugitive dust emissions occur from multiple-hearth roasters at several smelters. The quantity of dust generated by fluidization roasters can be as large as 75% of the roaster feed. Fluidization roasters are therefore fitted with cyclone separators for dust collection from the beds. The waste gas streams of fluidization roasters are considered to start at the cyclone outlets and the cyclones are considered as properly part of the process. Fluidization roaster dust emissions are probably larger than those from multiple-hearth roasters because of the larger degree of separation of the finer sized particles from the body of the charge in fluidization roasters.(6-63)

Particulate emissions in exit gases from a reverberatory furnace range from 14-40 kilograms per metric ton of copper matte produced. (6-63) The particulates consist of materials that leave the furnace in both the solid and vapor state. Material loading is a large source of fugitive dust.(6-63) A study of airborne trace element emissions from a reverberatory furnace at an operating smelter was undertaken in 1976.(6-73) Table 6-44 contains uranium and thorium analyses from this study for the furnace feed, furnace slag, matte, and dust from an electrostatic precipitator treating the furnace exit gas. The dust contained undetectable concentrations of uranium and thorium.

Particulate emissions from electric smelting furnaces are expected to be lower than those from reverberatory furnaces due to the lower exit gas volumes and more uniform gas flows.(6-63) The particulate composition should be the same as for reverberatory furnaces. Particulate emissions from flash smelting chambers should be about those from reverberatory furnaces. The particulates should have a lower volatile metal contact, however, which reflects lower feedstock concentrations of these metals.(6-63) Particle size analysis of converter dust from several Arizona smelters has revealed that approximately 56 percent of the dust has diameters between 25 and 32 microns in diameter.(6-63) Elemental analysis of the dust showed the iron, copper, and silicon content to range from 10-20, 10-19, and 5-15 weight percent, respectively. Pierce-Smith converters emit approximately 120 kilograms of particulate matter per metric ton of copper produced. Particulate emissions from a Hoboken converter should be comparable to those from a Pierce-Smith converter.

No data is available on particulate emissions from Noranda furnaces. Particulate loadings could be substantial, however. This is due to the feeders being continuously injected at high velocity into a moving gas stream. Solid wastes generated during blister copper production consist of mine waste rock, tailings from ore concentration, and slag from the smelter. Airborne particulate releases may

## TABLE 6-44

Uranium and Thorium Concentrations of Various
Solids at an Operating Reverberatory Furnace
Ref. (6-73)

| Substance | Uranium Concentration (ppm) | Thorium Concentration (ppm) |
|---|---|---|
| Furnace Food | 2 (1.7 pCi/g) | 4 |
| Furnace Slag | 9 (5.2 pCi/g) | 24 |
| Matte | $\leq$3 ($\leq$1.7 pCi/g) | $\leq$3 |
| Precipitator Dust | $\leq$2 ($\leq$1.7 pCi/g) | $\leq$3 |

result from dusting of piles of mine waste rock, tailings, and slag. No radionuclide analyses of mine waste rock and tailings are known. Generalizations as to the enrichment or depletion of tailings in uranium and thorium decay chain radionuclides relative to the ore are difficult to formulate on the basis of the physiochemical properties of the elements because of the lack of data on the mineralogy of uranium and thorium associated with copper deposits. Uranium and thorium have been found to be enriched in the reverberatory furnace slag relative to the furnace feed, matte, and emitted dust in a study of an operational smelter.(6-73) Uranium and thorium concentrations of 9ppm (5.2 pCi/g) and 24 ppm, have also been found for the furnace slag.(6-75)

Radon Releases

No data was found regarding radon releases from blister copper production. The quantity of radon capable of being released from the ore or any process solid or solution is, among other factors, dependent upon the radium content of the substances processed or of the wastes. No radium concentration data is known for copper ore, matte, slag, blister copper, or tailings. Assumptions may be made, however, as to which processes are likely to release radon based upon the nature of the processing. Processes involving agitation and heating, for instance, may tend to release some of the radon contained in the materials handled. The relative magnitudes of the process sources, however, are difficult to determine in view of the lack of radium data.

The drilling, blasting, loading, and ore transport of the mining operation affords a possibility for radon release. As previously discussed, radon daughter concentration levels have been found to present a health hazard in several underground copper mine atmospheres. Radon daughter level concentrations ranging up to 1.7 working levels have been found in a survey of seven undergound copper mines located in Arizona, Colorado, Michigan, Missouri and New Mexico. (6-66) Parent radon may have been released to the mine atmosphere through natural diffusion, convection through wall cracks and/or the mining operation. Crushing and grinding are potential sources of radon release during the concentrating stage of blister copper production. Drying, roasting, furnace smelting, and conversion could tend to release a portion of the radon contained in the material process due to elevated temperatures and extensive material handling (resulting in agitation) that characterize these processes.

Radon will be released by diffusion and convection from ore stockpiles, tailings, and slag piles. Uranium and thorium at an operating smelter have been found to be concentrated in furnace slag relative to the furnace feed, matte, and dust caught by a collector. Radium may very well display similar behavior. Furnace slag may constitute a technologically enhanced radon source.

## Airborne Radionuclide or Particulate Emission Controls

No controls are specifically utilized in the copper production industry for airborne radionuclide emissions. Controls are employed, however, for particulate and sulfur dioxide reduction, which also should reduce particulate radionuclide emissions. Table 6-45 summarizes the controls utilized for airborne particulate emissions. It should be noted that off-gas cooling from roasting, smelting, and converting, such as in waste heat boilers, will also result in particulate removal.

Water spraying is utilized at mining operations when necessary for fugitive dust control. The quantity of dust generated from blasting can also be reduced by proper blast design.(6-70) There are as many as 30 points at which controls are employed between mining and wet extraction.(6-70) Dusting at transfer points, such as conveyors, is reduced by spray bars and chemical dust suppressants. Baghouse

## TABLE 6-45

### Controls Utilized For Reducing Routine Airborne Particulate Emissions During The Production of Blister Copper

| Processing Stage | Emission | Controls |
|---|---|---|
| Mining | Fugitive Ore Dust | Water Sprinkling |
| Concentrating | Transfer Point Ore Dusting (i.e. such as from ore on conveyors) | Spray Bars, Chemical Suppressants |
|  | Milling | Baghouse Filters, Wet Scrubbers, Cyclones (Rarely) |
|  | Dusting From Tailing Piles | Slopes: Revegetation on bars tailing or overburden layer<br>Top: Chemicals stabilization when tailings are dry |
| Smelting | Fugitive Dust Emissions From Drying[a] | Balloon Flues, Cyclones, Baghouse Filters, Wet Scrubbers, Acid Plant Gas Cleaning Systems[b] |
|  | Roasting Off-Gas[c] | Settling Chambers, Balloon Flues, ESPs, Wet Scrubbers, Cyclones, Settling Flues, Acid Plant Gas Cleaning Systems[b] |
|  | Smelting Furnace Off-gas[c] | Settling chambers, Balloon Flues, Cyclones, ESPs, Acid Plant Gas Cleaning Systems[b] |
|  | Converter Off-gas[c] | ESPs, Cyclones, Wet Scrubbers, Acid Plant Gas Cleaning Systems[b], DMA Plant Gas Cleaning Systems[b] |
|  | Dusting from Furnace Slag Piles | Possibly overburden coverage. |

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a. Drying can take place at either the concentrator or smelter plant.

b. A typical sulfuric acid plant or dimethylaniline (DMA) plant gas cleaning system contains a dry ESP followed bu a wet scrubber and wet ESP (mist eliminator)

c. It should be noted that off-gas cooling, such as in waste heat boilers, will also result in particulate settling.

scrubbers are most commonly utilized for the reduction of particulate releases from process sources such as crushing. The baghouse filters utilized are cold gas stream baghouses.(6-70) They have an average collection efficiency of 99.5% for particles in the 0-5 microns in diameter range and 100% for larger sized particles.

Ducron UW4 scrubbers of various sizes are also commonly used. (6-70) The Ducron UW4 scrubber is a wet centrifugal type scrubber that operates in the range of 400-58,000 cfm and requires 8 gpm of water for 2000 scfm gas flow.(6-70) It has an efficiency of approximately 99% for dust particles having a diameter of greater than one micron and requires 7.5-10 horsepower. The carbon steel model with a fan has a capital cost of $5700 ($6133), whereas the stainless steel model with a fan has a $5000 ($5382) capital cost. Some plants use all baghouses, some all scrubbers, and others use both.(6-70) The choice of control device is essentially a function of economics, since both types of devices are capable of meeting dust control requirements.

Table 6-43 provides a summary of the gas cleaning technologies employed at 13 of the 16 operating smelters in the United States. (6-69, 6-70, 6-71) Dust collection from dryers is frequently complicated by moisture condensation in the warm gaseous effluent. The best dust removal method (on the basis of efficiency) for dryers installed at concentrator plants is wet scrubbing with the dust returned to the final stage of flotation. Balloon flues and other particulate removal equipment, such as baghouse filters, may be modified to handle the wet dust released from drying via multiple-hearth roasters. Balloon flues are oversized ducts in which dust particles settle by gravity when the flue gas velocity is sufficiently reduced. The dust removal efficiency is 30-60 percent. Although baghouses are effective dust collectors, they are rather troublesome. A caked product is produced that must be re-dried.(6-73) The drier located at the Inspiration, Arizona smelter utiizes a cyclone and baghouse filter for dust removal prior to off-gas release.(6-69). Cyclones are conical-shaped dust collectors that utilize centrifugal means for achieving particulate separation from the gas stream. They are generally utilized in smelting operations for coarse dust collection. Simple cyclones have efficiencies of greater than 82% for particles with diameters greater than 20 microns. Long-cone and multiple cyclones are more efficient.

Cyclones, settling chambers, and balloon flues are occasionally utilized for initial collection of large sized particulates from multi-hearth roasters. Fine particulates can be removed from multi-hearth roaster off-gas by hot gas electrostatic precipitators (ESPs). The off-gas can alternately be cooled and subsequently treated by an ESP or baghouse filter.(6-63) Two ESPs are utilized in series at the Tacoma, Washington smelter for treatment of cooled and combined multi-hearth roaster and smelting furnace off-gas prior to release.(6-71) Table 6-46 lists capital, direct, and total annual cost estimates for operation of a multiple-hearth roaster off-gas treatment system consisting of a single impingement wet scrubber followed by a cooling tower and ESP, respectively.(6-72) Off-gas from the ESP is to be fed to the gas cleaning system of a sulfuric acid plant, which is not considered in the cost estimates. Both large and small roasting plant model cases are considered. The large plant case considers the off-gases from four 200 TPD ten-hearth roasters operated in parallel, whereas the small plant case considers the off-gases from three 100 TPD ten-hearth roasters. The degree of off-gas treatment is such, for both cases, that there is no visible particulate matter in or detectable odor from treated off-gas. Model operating conditions are indicated in the table. The estimated costs are in 1971 (and 1978 dollars). Total annual costs (the sum of annualized capital and direct costs) of $165,257 and $81,421 (in 1978 dollars) are calculated for off-gas treatment by the above described system for the large and small plants, respectively.

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## TABLE 6-46

### Operating Conditions and Cost Estimates For A Copper Roaster Gas Cleaning System Consisting of a Wet Scrubber Followed by A Cooling Chamber and Electrostatic Precipitator (Ref 6-10)[a]

| | Small Plant | Large Plant |
|---|---|---|
| Effluent Gas Flow | 24,200 | 64,000 |
| °ACFM | 500 | 500 |
| F | 13,250 | 35,000 |
| SCFM | 8.9 | 8.9 |
| Moisture Content, Vol. % | | |
| Effluent | | |
| gr/ACF Solids | 10 | 10 |
| gr/ACF Mist | 2,060 | 5,500 |
| Cleaned Gas Flow | 14,350 | 37,900 |
| °ACFM | 105 | 105 |
| F | 12,120 | 32,000 |
| SCFM (Dry) | 9.1 | 9.1 |
| Moisture Content, Vol. % | | |
| Cleaned Gas | | |
| gr/ACF Solids | 0.06 | 0.06 |
| GR/ACF, Mist | 0.72 | 2.0 |
| Cleaning Efficiency, % Solids | 99.75 | 99.75 |
| Mist | | |
| (1) Gas Cleaning Device Cost | 183,670 (295,709) | 401,040 ( 645,674) |
| (2) Auxiliaries Cost[b] | 51,600 ( 83,076) | 93,550 ( 150,616) |
| (3) Installation Cost[c] | 94,390 (151,968) | 163,705 ( 263,565) |
| (4) Total Capital Cost | 329,660 (530,753) | 658,295 (1,059,855) |
| (5) Annualized Capital Cost | 32,966 ( 53,075) | 65,830 ( 105,986) |
| (6) Annual Direct Costs[d] | 17,606 ( 28,346) | 36,819 ( 59,279) |
| (7) Total Annual Cost | 50,572 ( 81,421) | 102,644 ( 165,257) |

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a. Costs are in 1971 dollars (1978 dollars). The cleaning system treats off-gas from three 100 TPD ten-hearth roasters operated in parallel for the large model plant and from four 200 TPD ten-hearth roasters operated in parallel for the small model plant. Off-gas from the ESP is to be fed into a sulfur acid production plant.

b. The auxiliaries cost includes the costs of fans, pumps, dampers, conditioning equipment, and dust disposal equipment.

c. The installation cost includes engineering foundations and support, ductwork, stack, electrical, paping, insulation, painting, supervision, startup, performance testing and other miscellaneous costs.

d. The direct cost includes maintenance, replacement parts, and utility costs.

The off-gases from all fluidization roasters are fed to sulfuric acid production plants for removal of $SO_2$. The $SO_2$ content of fluidization roaster off-gases can run as high as 12-14%, whereas the sulfur content in multiple hearth roaster gaseous effluents normally ranges between 3 and 6% due to air dilution. Almost complete dust removal is required for fluidization roaster off-gas before it can be fed to a sulfuric acid plant. Roaster off-gas at the Kennecott Hayden, Arizona smelter is treated in order by cyclones, a gravity precipitator, and a wet scrubber prior to release to the cleaning system of a sulfuric acid plant. This cleaning system may typically consist of a dry ESP followed by a wet scrubber and wet ESP (mist elimination). The fluidization roaster off-gas of the Morenci, Arizona smelter is treated by cyclones prior to release to the gas cleaning system of a sulfuric acid plant. An off-gas treatment system consisting of a wet scrubber, cooling tower, and ESP, as described for multihearth roaster gas cleaning, can be utilized for fluidization roaster off-gas. The costs would be the same as for the multihearth roasters of equivalent-sized plants.

Reverberatory furnace off-gas is most commonly passed through a waste heat boiler followed by an ESP prior to stack release. Spray coolers or balloon flues may precede the ESP. Overall particulate removal efficiencies range between 50 and 99.9 percent. Roaster and reverberatory furnace off-gases at the Asarco-Hayden, Arizona and Tacoma, Washington smelters are combined prior to ESP treatment.(6-71) Reverberatory furnace off-gases are not fed into sulfuric acid production plants following dust collection at any domestic smelter because of the low $SO_2$ concentrations. It has been successfully done, however, at a number of Japanese smelters.(6-63)

Tables 6-47 and 6-48 list cost estimates for the treatment of reverberatory furnace off-gas by ESP and wet scrubber systems.(6-72) The gas treatment systems serve the total off-gases from a pair of model reverberatory furnaces operated in parallel. A total of 1000

## TABLE 6-47

### Operating Conditions and Cost Estimates For An Electrostatic Precipitator Gas Cleaning System for Reverberatory Furnace Off-Gas (Ref 6-72)[a]

| | Medium Efficiency Case Small | Medium Efficiency Case Large | High Efficiency Case Small | High Efficiency Case Large |
|---|---|---|---|---|
| Effluent Gas Flow | | | | |
| °ACFM | 104,000 | 260,000 | 104,000 | 260,000 |
| F | 600 | 600 | 600 | 600 |
| SCFM | 52,000 | 130,000 | 52,000 | 130,000 |
| Moisture Content, Vol. % | 4.9 | 4.9 | 4.9 | 4.9 |
| Effluent Dust Loading | | | | |
| gr/ACF | 3.0 | 3.0 | 3.0 | 3.0 |
| lb/hr | 2,700 | 6,800 | 2,700 | 6,800 |
| Cleaned Gas Flow | | | | |
| °ACFM | 104,000 | 260,000 | 104,000 | 260,000 |
| F | 600 | 600 | 600 | 600 |
| SCFM (Dry) | 52,000 | 130,000 | 52,000 | 130,000 |
| Moisture Content, Vol. % | 4.9 | 4.9 | 4.9 | 4.9 |
| Cleaned Gas | | | | |
| gr/ACF | .045 | .018 | .015 | .015 |
| lb/hr | 40 | 40 | 13.4 | 33.4 |
| Cleaning Efficiency, % | 98.5 | 99.4 | 99.5 | 99.5 |

| | | Medium Efficiency Case Small | Medium Efficiency Case Large | High Efficiency Case Small | High Efficiency Case Large |
|---|---|---|---|---|---|
| (1) | Gas Cleaning Device Cost | 175,510 (282,571) | 395,895 ( 637,391) | 221,037 (355,870) | 401,312 ( 646,112) |
| (2) | Auxiliaries Cost[b] | 52,470 ( 84,477) | 91,712 ( 147,656) | 55,633 ( 89,569) | 93,810 ( 151,034) |
| (3) | Installation Cost[c] | 206,887 (333,088) | 385,206 ( 620,182) | 269,923 (434,576) | 409,587 ( 659,435) |
| (4) | Total Capital Cost | 434,867 (700,136) | 872,813 (1,405,229) | 546,593 (880,015) | 904,709 (1,456,581) |
| (5) | Annualized Capital Cost | 43,487 ( 70,014) | 87,281 ( 140,522) | 54,659 ( 88,001) | 90,461 ( 145,642) |
| (6) | Annualized Direct Cost[d] | 9,923 ( 15,976) | 16,561 ( 26,663) | 10,923 ( 17,586) | 16,561 ( 26,663) |
| (7) | Total Annual Cost | 53,410 ( 85,990) | 103,342 ( 166,381) | 65,582 (105,587) | 107,022 ( 172,035) |

---

a Costs are 1971 dollars (1978 dollars). The precipitator treats offgas from a pair of reverberatory furnaces. A total of 1000 TPD of matte are produced by the furnaces of the large smelter case whereas 400 TPD is produced in the small smelter case.

b The auxiliaries cost includes the costs of fans, pumps, dampers, gas conditioning equipment, and dust disposal equipment.

c The installation costs includes engineering, foundation and support, ductwork, stack, electrical, piping, insulation, painting, supervision, startup, performance testing and other miscellaneous costs.

d The direct cost includes maintenance, replacement parts, and utility costs.

## TABLE 6-48

### Operating Conditions and Cost Estimates For A Wet Scrubber Gas Cleaning System for Reverberatory Furnace Off-Gas (Ref 6-10)[a]

| | Medium Efficiency Case | | High Efficiency Case | |
|---|---|---|---|---|
| | Small | Large | Small | Large |
| Effluent Gas Flow | | | | |
| °ACFM | 104,000 | 260,000 | 104,000 | 260,000 |
| F | 600 | 600 | 600 | 600 |
| SCFM | 49,500 | 124,000 | 49,500 | 124,000 |
| Moisture Content, Vol. % | 4.9 | 4.9 | 4.9 | 4.9 |
| Effluent Dust Loading | | | | |
| gr/ACF | 3 | 3 | 3 | 3 |
| lb/hr | 2,700 | 6,800 | 2,700 | 6,800 |
| Cleaned Gas Flow | | | | |
| °ACFM | 85,000 | 213,000 | 85,000 | 213,000 |
| F | 250 | 250 | 250 | 250 |
| SCFM (Dry) | 50,740 | 127,400 | 50,740 | 127,400 |
| Moisture Content, Vol. % | 23.5 | 23.5 | 23.5 | 23.5 |
| Cleaned Gas | | | | |
| gr/ACF | 0.055 | 0.022 | 0.015 | 0.015 |
| lb/hr | 40 | 40 | 11.0 | 28.4 |
| Cleaning Efficiency, % | 98.5 | 99.4 | 99.6 | 99.6 |

| | Medium Efficiency Case | | High Efficiency Case | |
|---|---|---|---|---|
| | Small | Large | Small | Large |
| (1) Gas Cleaning Device Cost | 38,750 ( 62,388) | 68,000 ( 109,480) | 38,750 ( 62,388) | 68,000 ( 109,480) |
| (2) Auxiliaries Cost[b] | 117,400 (189,014) | 289,500 ( 466,095) | 138,400 (222,824) | 339,500 ( 546,595) |
| (3) Installation Cost[c] | 50,000 ( 80,500) | 85,000 ( 136,850) | 63,000 (101,430) | 104,000 ( 167,440) |
| (4) Total Capital Cost | 206,150 (331,902) | 442,500 ( 712,425) | 240,150 (386,642) | 511,500 ( 823,515) |
| (5) Annualized Capital Cost | 20,615 ( 33,190) | 44,250 ( 71,243) | 24,015 ( 38,664) | 51,150 ( 82,352) |
| (6) Annualized Direct Cost[d] | 99,800 (160,678) | 188,300 ( 303,163) | 238,400 (383,824) | 343,400 ( 552,874) |
| (7) Total Annual Cost | 120,415 (193,868) | 232,550 ( 374,406) | 262,415 (422,488) | 394,550 ( 635,226) |

---

[a] Costs are 1971 dollars (1978 dollars). The system treats gases from a pair of reverberatory furnaces. A total of 1000 TPD of matte are produced by the furnaces of the large smelter case whereas 400 TPD is produced in the small smelter case.

[b] The auxiliaries cost includes the costs of fans and motors, pumps, dampers, conditioning equipment, and dust disposal equipment.

[c] The installation costs includes engineering, foundation and support, ductwork, stack, electrical, piping, insulation, painting, supervision, startup, performance listing and other miscellaneous costs.

[d] The direct cost includes maintenance, replacement parts, and utility costs.

TPD of matte are produced by the furnaces of the large smelter model case, whereas 400 TPD are produced in the small model smelter. Both intermediate and high efficiency particulate removal cases are provided for each treatment type. The intermediate level cleanup cases satisfy the Los Angeles County Air Pollution Control District ordinances (Rule 54 of the Air Pollution Control District of Los Angeles County). High efficiency particulate removal cases produce emissions that have no visible particulate matter or detectable odor. A listing of operational conditions for each case are included in Tables 6-47 and 6-48. The minimum particulate removal efficiency for any case is 98.5%. All costs are listed in 1978 dollars updated from 1971 costs. The capital costs for the electrostatic precipitator treatment cases are 1.7-2.1 times larger than those for the corresponding wet scrubber cases. The total annual costs for the ESP cases are 0.25-0.44 times lower, however, than for the corresponding wet scrubber cases. This is a result of the lower operating costs for ESPs regardless of plant size or efficiency.(6-72)

Off-gases from each of the three operating domestic electric furnace smelters are fed into the gas cleaning systems of sulfuric acid manufacturing plants.(6-63) The gas streams from each electric smelter are combined with the off-gas from another furnace, such as a fluidized roaster or converter, prior to passage to the sulfuric acid plant. Particulate removal from cooled electric furnace off-gas of the Inspiration, Arizona smelter prior to channeling to the acid plant gas cleaning system is accomplished by a cyclone followed by an ESP. The off-gas is combined with those of the converters after the ESP.(6-69, 6-71)

Off-gas from the one operating domestic flash smelter is fed to the gas cleaning system of a sulfuric acid plant.(6-63) The dust cleaning systems utilized prior to the acid plant are not known. Satisfactory methods for particulate removal, however, include ESPs and wet scrubbers.

Converter off-gas is usually fed to a sulfuric acid plant and therefore requires almost complete prior particulate removal. Other methods for off-gas disposal are direct stack release (including the Asarco-Hayden, Arizona; Douglas, Arizona, McGill, Nevada*, White Pine, Michigan, and the Anaconda, Montana smelters) and processing in a dimethylaniline (DMA) scrubbing plant (Tacoma, Washington smelter*).(6-71) Off-gas fed to a DMA plant requires almost complete particulate removal.(6-70) The technologies employed for particulate removal from converter off-gas prior to disposal are the same as those employed for roaster and smelting furnace off-gas streams. Cyclones, ESPs, and wet scrubbers are commonly utilized. Converter gases are often combined with the off-gases from other furnace types prior to stack release or passage to the gas cleaning system of an acid plant. The one domestic smelter in which Hoboken converters are used mixes the off-gases from these furnaces with that from an electric furnace following cooling, passage through a cyclone, and ESP treatment. The combined off-gases are fed to an acid plant gas cleaning system.(6-71)

Four potential methods for operational stabilization of tailing and slag piles against dusting are: physical stabilization, chemical stabilization, vegetative stabilization, and combined method stabilization, such as chemical-vegetative. Physical stabilization usually involves coverage of the tailings with overburden, coverage with bark, mulching, or sprinkling water onto the tailings surface to keep them wet.(6-77) Chemical stabilization entails the application to the tailings of a material that will interact with the tailings to form an erosion resistant crust.

Vegetative stabilization ideally consists of the establishment of a self perpetuating vegetative cover on the tailings. The initial vegetative cover should eventually lead to a cover of local flora by ecological succession, requiring no irrigation or other special care.(6-77) The development of vegetation directly onto tailings is sometimes difficult due to the deficiency in plant nutrients, the possible presence of excessive salt concentrations and heavy metal plant poisons, possible sand blasting and/or burial, and varying growth conditions. Fertilization, neutralization and prevention of sand blasting and/or burial may be necessary on a continuous basis. The former can be prevented by water sprinkling during plant growth, coverage with soil, hydroseeding using emulsion-filled matting, and a combination chemical-vegetative procedure.(6-77) One method, hydroseeding, involves blowing a seed, fertilizer, and wood or paper pulp slurry over the surface to be stabilized. The wood or paper pulp serve as protection during plant growth.(6-77)

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*Part of the converter off-gas flow

Vegetative stabilization utilizing hydroseeding has been undertaken for the Cyprus Pima copper tailings in Arizona.(6-78) Research involving the use of buried organic layers and tailings pelletization to enhance vegetative stabilization has been published regarding the Kennecott tailings in Utah.(6-79) Copper tailings in Holden Valley, Washington were used to test the growth effectiveness of several plant types on raw tailings and on tailings treated with lime, sewage, sludge, and fertilizers.(6-79)

### Radon Controls

Radon exhalation from ore stockpiles may be reduced by water sprinkling or chemical stabilization. Spray bars may reduce radon releases from ores on conveyors and at other ore transfer locations. Wet scrubbers utilized for particulate and/or sulfur dioxide removal from off-gas generated by drying, roasting, furnace smelting, and converting or from fugitive emissions from ore concentrating are possibily capable of removing some radon by virtue of its solubility in water. Subsequent treatment of the water for recycling might, however, release the radon. Operational water sprinkling of tailing and slag piles or the application of chemical stabilizers may reduce radon exhalation. Coverage of the piles with overburden will reduce the exhalation rate. The reduction will be dependent upon many factors including the depth of cover, degree of cover compaction, and cover moisture content.

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# CHAPTER II

## Section 7: Selected Non-Nuclear Facilities

### Geothermal Power Production

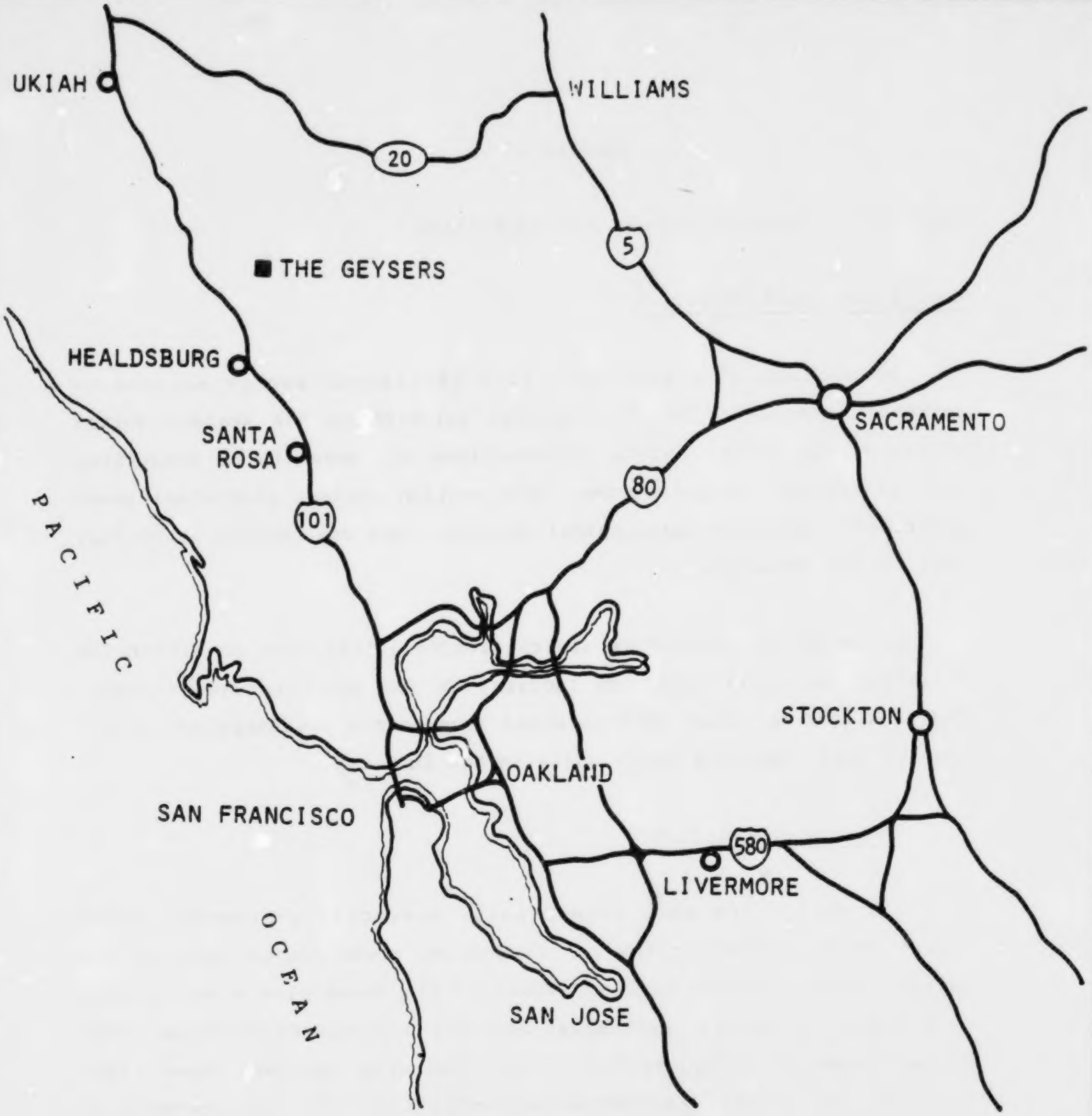
Production of electricity from geothermal energy sources is currently considered to be a partial solution to the western United States energy needs. Since radionuclides are known to be associated with geothermal energy sources, this section reviews geothermal power generation, possible radiological emissions and any control technology used by the industry.

An extensive literature search yielded little data on either the radiation asociated with the industry or the controls used therein. The data that do exist were obtained from source documents and direct contact with cognizant individuals in the industry.

### Industry Description

Currently, the only commercially operating geothermal power plants in the United States are the Geyser Power Plants owned by The Pacific Gas & Electric Company (PG&E).(7-1) These plants are located in a region of natural geothermal activity approximately 130 km north of San Francisco (Figures 7.1, 7.2). The area has been known since 1847 for its natural geothermal activity, i.e., for the presence of fumaroles, or steam emitting vents.

Within this area, PG&E has established eleven electrical generating units. The first of these was online in 1960 with a capacity of 11 megawatts. The last plant was established in 1975 and has a generating capacity of 106 megawatts.(7-1) The total generating capacity of the field is currently 502 megawatts, equivalent to the


UKIAH
WILLIAMS
20
5
THE GEYSERS
HEALDSBURG
SACRAMENTO
SANTA ROSA
80
101
PACIFIC
STOCKTON
OAKLAND
SAN FRANCISCO
580
LIVERMORE
OCEAN
SAN JOSE

FIGURE

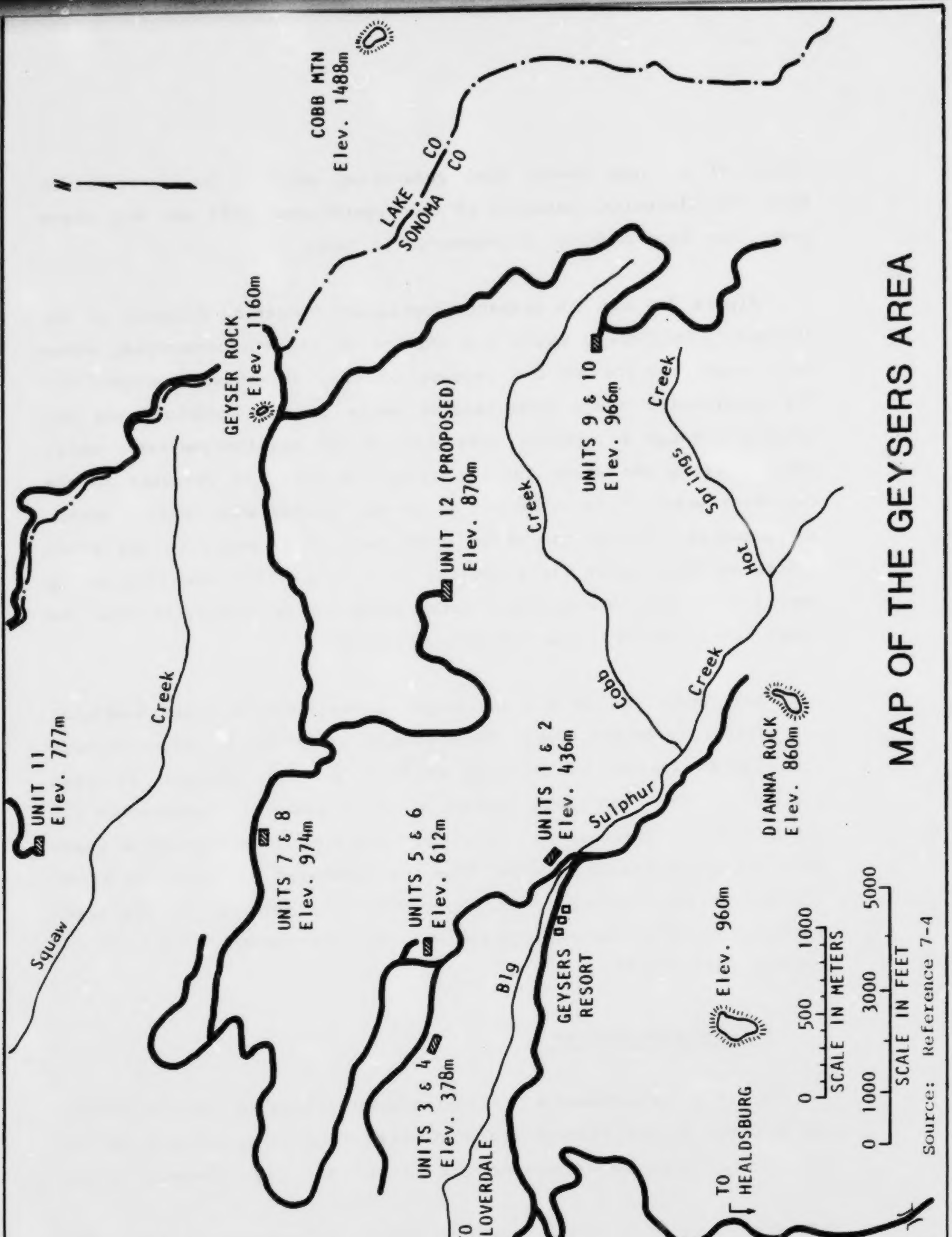
GENERAL AREA MAP OF PART OF NORTHERN CALIFORNIA INDICATING THE LOCATION OF THE GEYSERS GIOTHERMAL FIELD

0 10 20 40

SCALE IN MILES

Source: Reference 7-1

**DAMES & MOORE**


COBB MTN
Elev. 1488m
N
LAKE CO
SONOMA CO
GEYSER ROCK
Elev. 1160m
UNIT 12 (PROPOSED)
Elev. 870m
UNITS 9 & 10
Elev. 966m
Creek
Springs
Hot
Creek
Cobb
Creek
UNIT 11
Elev. 777m
Creek
Squaw
UNITS 7 & 8
Elev. 974m
UNITS 5 & 6
Elev. 612m
UNITS 1 & 2
Elev. 436m
Sulphur
Big
GEYSERS
RESORT
DIANNA ROCK
Elev. 860m
Elev. 960m
UNITS 3 & 4
Elev. 378m
TO
← CLOVERDALE
TO
HEALDSBURG
0 500 1000
SCALE IN METERS
0 1000 3000 5000
SCALE IN FEET
SUMMIT
Elev.
824m

MAP OF THE GEYSERS AREA

Source: Reference 7-4

DAMES & MOORE

FIGURE 7.2

output of a large fossil fuel generating unit*. The installation date, net electrical capacity of each operational unit and full steam power flow (pre-turbine) is presented in Table 7-1.

Figure 7.3 and 7.4 present generalized operating diagrams of the systems. Initially, wells are drilled to tap the underlying steam zone which results in the release of dry, superheated steam.(7-1) The superheated steam from several wells is then combined and delivered through a particle separator to the turbine-generator unit. After leaving the steam turbine area, the steam is released to the condensor where it is condensed by direct washing with cooling water. Approximately 80% of the steam condensate is released to the atmosphere as water vapor via a cooling tower.(7-1) The remaining 20% is pumped from the cooling power water basin to be reinjected into the steam field reservoir via reinjection wells.

Also contained in the steam are non-condensable gases averaging 0.4 percent by weight.(7-4) These consist primarily of carbon dioxide with lesser amounts of hydrogen sulfide, methane, ammonia, nitrogen and radon. Only about one percent of these gases are returned to the steam field. Previous to 1976, the remaining non-condensable gases were either partially removed from the condenser by gas ejectors or carried to the cooling tower where they were released to the atmosphere. By 1976, the gas ejector effluent was ducted directly to the cooling tower.(7-3)

## Radionuclide Sources

In 1974, measurements of radon concentrations in the non-condensable gases of the release stack prompted PG&E to initiate a comprehensive program to determine the extent and significance of the

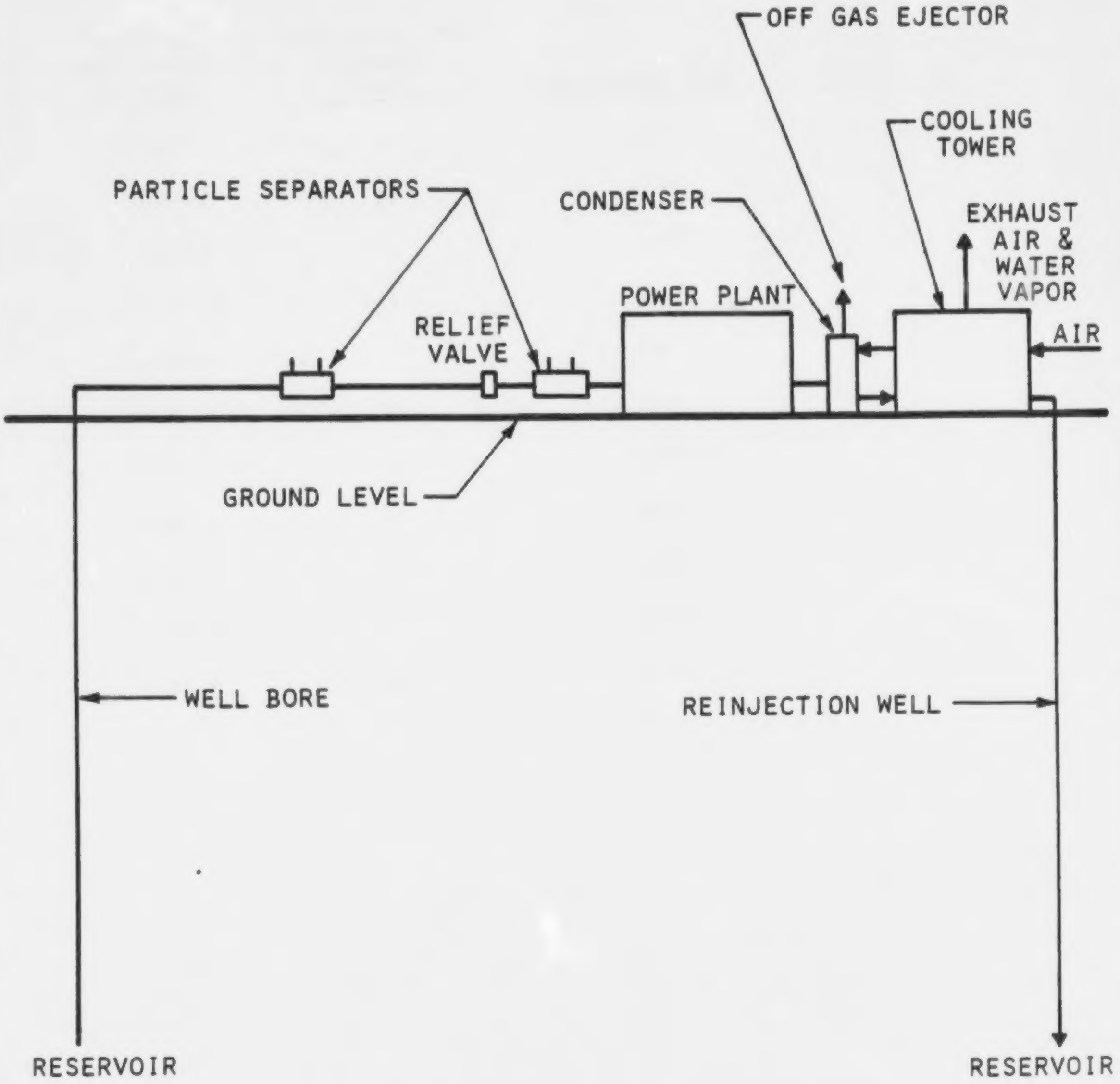
---

*It should be noted that the entire worldwide capacity of electrical power generation by geothermal power is only about 1000 megawatt. (7-2)

## TABLE 7-1

### Installation Date, Net Electrical Installed Capacity, and Steam Flow Rates at the Geysers, California, Geothermal Power Plant

| Unit Number | Year Installed | Net Electrical Capacity (MWe) | Full Power Steam Flow (kg/hour) |
|---|---|---|---|
| 1 | 1960 | 11 | $1.1 \times 10^5$ |
| 2 | 1963 | 13 | $1.2 \times 10^5$ |
| 3 | 1967 | 27 | $2.4 \times 10^5$ |
| 4 | 1968 | 27 | $2.4 \times 10^5$ |
| 5 | 1971 | 53 | $4.4 \times 10^5$ |
| 6 | 1971 | 53 | $4.4 \times 10^5$ |
| 7 | 1972 | 53 | $4.4 \times 10^5$ |
| 8 | 1972 | 53 | $4.4 \times 10^5$ |
| 9 | 1973 | 53 | $4.4 \times 10^5$ |
| 10 | 1973 | 53 | $4.4 \times 10^5$ |
| 11 | 1975 | 106 | $8.7 \times 10^5$ |

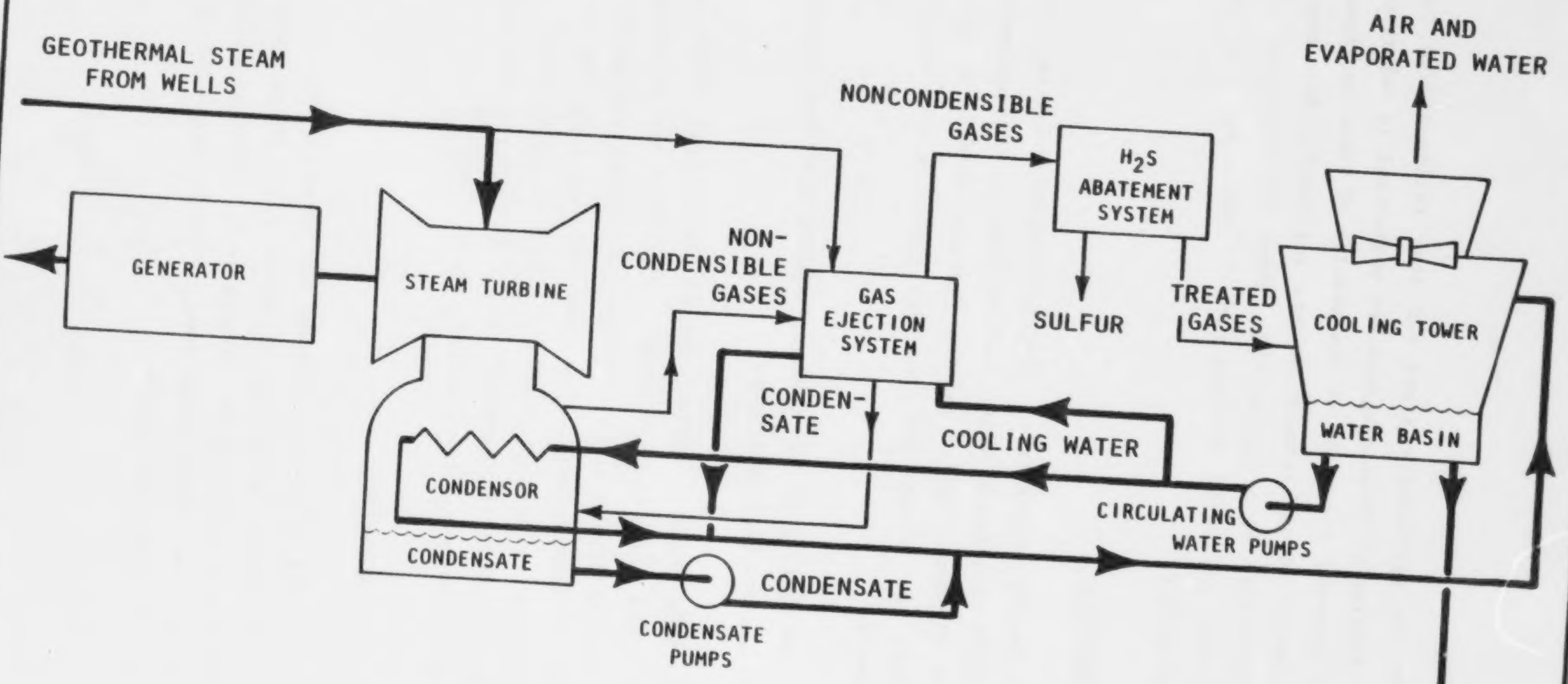

OFF GAS EJECTOR
COOLING TOWER
PARTICLE SEPARATORS
CONDENSER
EXHAUST AIR & WATER VAPOR
POWER PLANT
RELIEF VALVE
AIR
GROUND LEVEL
WELL BORE
REINJECTION WELL
RESERVOIR
RESERVOIR

SCHEMATIC DIAGRAM OF THE TYPICAL SYSTEM AT THE GEYSERS

Source: Reference 7-4

DAMES & MOORE

FIGURE 7.3


GEOTHERMAL STEAM FROM WELLS
GENERATOR
STEAM TURBINE
NON-CONDENSIBLE GASES
GAS EJECTION SYSTEM
NONCONDENSIBLE GASES
$H_2S$ ABATEMENT SYSTEM
SULFUR
TREATED GASES
AIR AND EVAPORATED WATER
COOLING TOWER
WATER BASIN
CONDEN-SATE
COOLING WATER
CONDENSOR
CONDENSATE
CIRCULATING WATER PUMPS
CONDENSATE
CONDENSATE PUMPS
EXCESS CONDENSATE TO REINJECTION WELLS

GENERAL GEOTHERMAL POWER CYCLE

Source: Reference 7-1

FIGURE 7.4

radioactivity in the pre-turbine steam and that released from the site.(7-4) The results of these programs are summarized in reference 7-1. Table 7-2 presents a portion of the results of these programs. A complete discussion of the summary of data and results from these programs is reproduced in Appendix IIC. From the table, it can be calculated that the total maximum rate of radon input to the turbines is 1.43 Ci/day.

## Emission Controls

The major control system is the hydrogen abatement system. This system is designed to scrub hydrogen sulfide from the non-condensible gas stream and to catalytically oxidize hydrogen sulfide to reduce sulfur emissions. The exhaust gas from this system is then ducted to the cooling towers.

To date, the effects of the hydrogen sulfide abatement system on radon releases has not been determined.

Although not a primary control, the use of cooling towers tends to dilute the input radon concentrations. The large air volume drawn through the cooling towers mixes with the non-condensible gases thus lowering their concentrations. The final exhaust from the cooling towers is measured to be less than 2.0 pCi/l of radon.(7-1) This concentration is within the current 3 pCi/l above background concentrations established by the State of California.(7-4)

## Summary and Conclusions

The Pacific Gas & Electric Company is presently not using any primary type of control technology to reduce radon-222 emission from the geothermal power plants in the Geysers area. However, the effects of currently utilized technologies seem to reduce radon-222 emission concentrations to background levels.

## TABLE 7-2

### Radon Content of Pre-Turbine Steam

| Unit Number | Full Power Steam Flow (kg/hr) | Radon Concentration (nCi/kg steam) | Radon Inlet Rate (mCi/hr) |
|---|---|---|---|
| 1 | $1.1\text{x}10^5$ | 23.9 | 2.63 |
| 2 | $1.2\text{x}10^5$ | 22.4 | 2.69 |
| 3 | $2.4\text{x}10^5$ | 30.5 | 7.32 |
| 4 | $2.4\text{x}10^5$ | 21.0 | 5.04 |
| 5 | $4.4\text{x}10^5$ | 16.2 | 7.13 |
| 6 | $4.4\text{x}10^5$ | 16.2 | 7.13 |
| 7 | $4.4\text{x}10^5$ | 9.0 | 3.96 |
| 8 | $4.4\text{x}10^5$ | 9.5 | 4.18 |
| 9 | $4.4\text{x}10^5$ | 8.3 | 3.65 |
| 10 | $4.4\text{x}10^5$ | 5.0 | 2.20 |
| 11 | $8.7\text{x}10^5$ | 15.7 | 13.66 |
| Total | $4.22\text{x}10^5$ | 177.7 | 59.59 |

## Ground Water Treatment Plants

Many municipalities depend on ground water to wholly or partially supplement their water needs. In certain states such as Illinois and Iowa high radium concentrations have necessitated the need to treat the water to lower the radium-226 concentrations.(7-5, 7-6) As radon-222 is a decay product of radium-226, a potential exists for the atmospheric release of radon from ground water treatment plants.

This section reviews radon in ground water, and provides an assessment of any control technologies used by municipal ground water supply facilities to limit the discharge to the environment.

An extensive literature search yielded some data on radon in ground water but little on any controls used therein. Whatever data existed was supplemented by direct contact with various organizations, state agencies and responsible individuals.

The facilities under consideration were limited to those with a capacity of 1 to 10 million gallons per day. Those below 1 million gallons per day are not considered representative (small wells, etc), while those greater than 10 million gallons per day are typically surface water treatment plants. A list of approximately 1600 facilities in the capacity of interest was compiled after conversations with various state agencies.

### Radon in Ground Water

The measured concentrations of radon-222 in potable water samples collected in seven areas throughout the United States have shown a wide degree of variability, ranging from 19 pCi/l to 1,130,000 pCi/l.(7-7) Table 7-3 presents a summary of the range of concentrations measured for each area. The maximum permissible concentration (MPC) for radon-222 in water is 2000 pCi/l as published in NBS

## TABLE 7-3

## Measured Rn-222 Concentrations in Ground Water Samples(a)

| State | Rn-222 Concentrations (pCi/l) |
|---|---|
| Maine | 53,700(b) |
| New Hampshire | 2,500-1,130,000(c) |
| Washington, North Dakota, Montana, Idaho | 19-5,600 |
| Utah | 400-1800 |
| Texas | 20-27,000 |
| Houston, Texas | 500-2,000(d) |

---

(a) Reference 7-1.
(b) Average of 226 samples.
(c) Twenty-six samples with an average of 101,000 pCi/l.
(d) Ground water is 75% of supply.

Handbook #52. The maximum concentrations measured for each area, except Utah and Houston, Texas, exceeded the maximum permissible concentration (MPC). The average radon-222 concentration determined for both New Hampshire and Maine exceeded the $MPC_{(w)}$ for radon-222 by more than an order of magnitude.

## Control of Airborne Emissions

Contact was established with the responsible agencies in the states of New Hampshire and Maine.(7-8,7-9) The survey was limited to the states of New Hampshire and Maine on the basis of the elevated radon-222 concentrations shown in Table 7-3. It was initially assumed that the responsible state agencies might have data on the effects of these controls on the radium-226 progeny, radon-222. The survey was conducted to determine if the state required any type of radon-222 controls, recommended any radon-222 control, had any guidelines for control of radon-222 concentrations in water, and if they were aware of any studies or data that indicated the effects of standard water treatment practices on radon-222 concentrations in municipal supplies.

The results of the survey revealed that there were no control technologies currently being recommended to limit radon-222 emissions during water treatment, the effect of standard water treatment processes on radon-222 concentrations in water is unknown and in areas of elevated radon-222 concentrations in water there are no suggested guidelines concerning radon-222 concentrations in potable water.

## Conclusion

At the present time there are no control technologies being utilized by municipal ground water treatment facilities to either control radon-222 concentrations in water or to limit radon-222 releases during standard processing operations.

Also, although some facilities attempt to reduce radium-226 concentrations in potable water, effects of these controls on radon-222 release are unknown. As these treatment plants aerate the water as part of their standard treatment procedures, they probably increase radon emanation to the atmosphere.

## REFERENCES

II.7-1 Anspaugh, L.R. Final Report on the Investigation of the Impact of the Release of Rn-222, Its Daughters and Precursors at the Geysers Geothermal Field and Surrounding Area. Livermore Ca: Lawrence Livermore Laboratory. Environmental Science Division, March, 1978.

II.7-2 Schieler, L. "Geothermal Effluents, Their Toxicity and Prioritization," in Proceedings of the First Workshop on Sampling Geothermal Effluents. Las Vegas, Nevada. October 20-21, 1975. PB-258-067, 1976.

II.7-3 Serpa, D.P. and Anspaugh, L.R. Summary Report of Geysers Radiological Measurement Program. Pacific Gas and Electric. Department of Engineering Research, Report #420-78.41, May, 1978.

II.7-4 Soinski, A.J. et al. "Field Sampling of Radioactive Geothermal Effluents," in Proceedings of the First Workshop on Sampling Geothermal Effluents. Las Vegas, Nevada. October 20-21, 1975. PB-258-067, 1976.

II.7-5 Schlieselman, R.J. Determination of Radium Removal Efficiencies in Iowa Water Supply Treatment Process. Technical Note ORP/TAD-76-1, April, 1976.

II.7-6 Bennett, D.L., et al. Determination of Radium Removal Efficiencies in Illinois Water Supply Treatment Process. Technical Note ORP/TAD-76-2, May, 1976.

II.7-7 United States Environmental Protection Agency. Office of Radiation Programs. Radiological Quality of the Environment. EPA 520/1-76-010, May, 1976.

## REFERENCES (cont'd)

II.7-8 New Hampshire. Department of Public Health. Water Supply and Pollution Control Laboratory. Personal communication, R. Palydon, 1979.

II.7-9 Maine. Division of Public Health. Health Engineering Section. Personal communication, C. Tappan, 1979.

# APPENDIX IIA

## Sample HEPA System Costs and Specifications

# APPENDIX II.A

## Introduction

This appendix considers the capital and annual operating costs associated with HEPA filter systems, presents an example cost calculation for an air cleaning system including HEPA filters, and gives a sample equipment specification for a HEPA filter.

The appendix includes: a brief background section; a discussion of HEPA system components that contribute the major part of the costs associated with the system, and unit costs for these components, details of an air cleaning system representative of a large nuclear installation and the capital and annual operating costs for the system; and a sample equipment specification for HEPA filters.

## Background

As previously discussed, the applicability of an airborne emission control technology for a specific facility is determined after an evaluation of several factors, among which are the potential for airborne contamination within the facility, the relative radiotoxicities of the specific isotopes being handled, and the quantity of radioactive material being handled. After the requirement of an airborne emission control technology has been established, the specific control technology applied to the airborne effluent of a facility is selected by a cost effectiveness evaluation of those control technologies that enable the facility to conform with the applicable criteria and regulations.

Filter systems which include HEPA filters (HEPA systems) are usually utilized when the aerodynamic diameter of the contaminant to be controlled is in the micrometer range and a high number efficiency is indicated. An extensive discussion of HEPA filters, HEPA system components, and system design principles can be found in references IIA-1 and IIA-2. Several factors pertinent to this appendix are summarized below.

The design of HEPA systems are influenced by many factors. The major influencing factors are: the volumetric flow rate of the system; the nature, size and concentration of the dust to be controlled; and the decontamination factor (efficiency) required. In addition, the permissible pressure rise, space available for filter installation, chemical composition of the carrying effluent stream, specific facility function and design, and minimum interval between servicings also contribute to the design of HEPA systems. Each of these factors may become the most important factor depending on the specific facility function and design.

The discussion of the effects, under varying conditions, of the above factors on HEPA system design is beyond the scope of this work. Only the three factors denoted as "major" are considered below.

The number and sizes of the HEPA filters to be used are essentially determined by the volumetric flow rate of the system. HEPA filters are manufactured in varying sizes. Standard HEPA sizes currently commercially available are given in Table A-1. For example, for a flow rate of 10,000 cfm, one can chose 10 HEPAs each rated at 1000 cfm or 80 HEPAs each rated at 125 cfm. Other considerations determine the eventually chosen specific combination.

The dust holding capacity of a filter under operational conditions is a function of the concentration, type, shape, size, density and "stickiness" of the dust particles to be controlled. Dust holding capacity is usually a secondary consideration for HEPA filters if they are preceeded by pre-filters, particularly in high-concentration applications. However, the nature, size and concentration of the dust determines the filter life.

## TABLE A-1

### Standard HEPA Filter Sizes

| Face Dimensions (inches) | Depth (inches) | Design Airflow Capacity at Clean-Filter Resistance of 1.0 in.w.g. (scfm) |
|---|---|---|
| 24 x 24 | 11 1/2 | 1000 |
| 24 x 24 | 5 7/8 | 500 |
| 12 x 12 | 5 7/8 | 125 |
| 8 x 8 | 5 7/8 | 50 |
| 8 x 8 | 3 1/16 | 25 |

* Source : Reference IIA-1

## TABLE A-2

### Relative Costs of HEPA Filters*

| Casing Material | Separator Material | | | |
|---|---|---|---|---|
| | Untreated Asbestos | Aluminum Foil | Treated** Asbestos | Plastic |
| Wood | 1.00 | 1.02 | 1.08 | 1.71 |
| Carbon Steel*** | 1.13 | 1.16 | 1.22 | 1.89 |
| Stainless Steel | 1.96 | 1.99 | 2.04 | 2.69 |

* Source : Reference IIA-1

** Qualified for moisture and corrosion resistance in accordance with procedures established by ERDA.

*** Cadmium-plated or chromized.

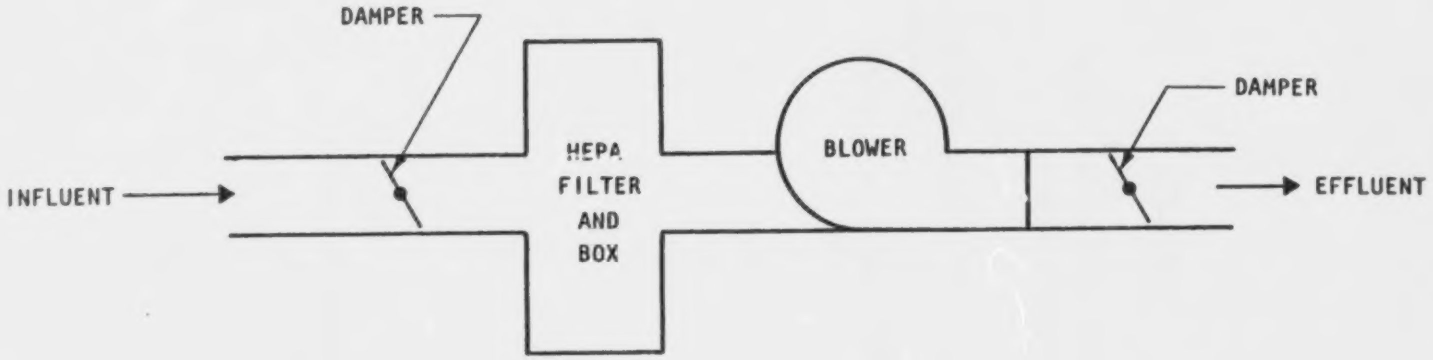
The third factor, the efficiency required, varies from facility to facility. This factor determines how many banks of HEPA filters in series are required, and whether in-place DOP testing capability is necessary. The most frequently quoted decontamination factor (DF) for HEPA filters is 3333 for particles greater than 0.3 um, however, in actual performance with in-place DOP testing, DFs of 5000 have been obtained (IIA-1). Theoretically, two filters in series would have a DF of up to $2.5x10^7$. However, in practice this varies with specific installation and operating conditions.

## HEPA System Components and Unit Costs

Almost all HEPA systems have certain basic components associated with them. These components, which are shown in Figure A.1, are the HEPA filter, blower/fan driving the stream, dampers/flues for isolation of components, ducts to channel the stream, and overall system structure. Components which precede the HEPA filter, such as prefilters and chemical treatment components, are not considered in this section since they depend on the specific facility function and design. It will be assumed that the physical and chemical characteristics of the stream that is introduced into the HEPA system are within performance limits.

The basic costs for each HEPA filter, for several casing and separator materials, are given in Table A-2. Table A-3 presents the relative costs of various HEPA filters, including the casing material and the separator material variability. Installed costs of HEPA filters vary widely depending on the system and cannot be quoted. However, installed cost (labor and material) of a 1000-cfm HEPA filter was estimated to be $2200 (IIA-3) for the system considered in that reference.

The major requirement for a blower/fan in a HEPA system is its ability to perform safely and efficiently over a much larger variation


DAMPER
DAMPER
INFLUENT
HEPA
FILTER
AND
BOX
BLOWER
EFFLUENT

BASIC HEPA FILTER SYSTEM AND COMPONENTS

FIGURE A.1

## TABLE A-3

Standard HEPA Filter Costs*
(1979 dollars)

| Dimensions | Separators | Wood | Stainless Steel | Chromium Steel |
|---|---|---|---|---|
| | | Casing Material | | |
| 8x 8x5 7/8 | Foil | 36 | | |
| | None | 41 | | |
| 12x12x5 7/8 | Foil | 73 | 87 | |
| | None | 85 | 101 | |
| 24x24x5 7/8 | Foil | 89 | | |
| | None | 103 | | |
| 24x24x11 1/2 | Foil | 133 | 253 | 156 |
| | None | 163 | 345 | 189 |
| 24x36x11 1/2 | None | 166 | | |

---

* Source : Reference IIA-5, Costs for filters at rated efficiencies of 99.97% for particles with aerodynamic diameter greater than 0.3 micrometers. Costs include flame retardant and flanges with each casing.

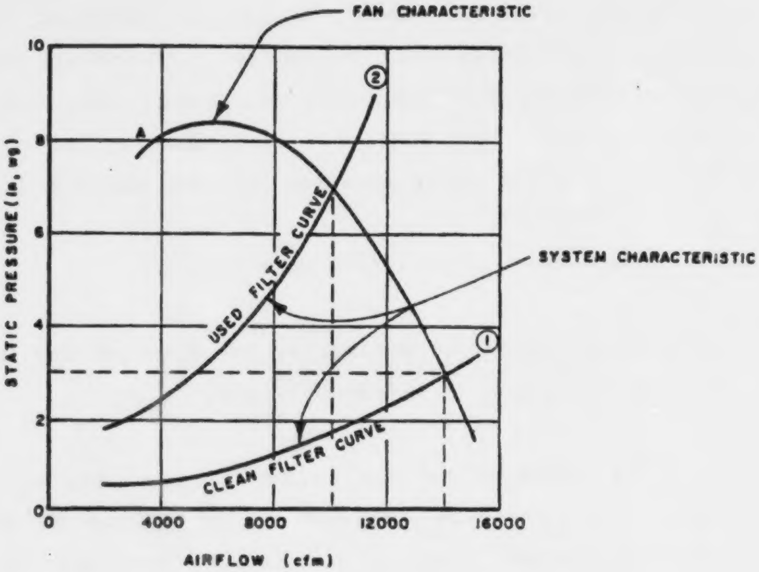
of resistance (caused by dust loading) than more conventional systems. An example of blower and filter characteristic curves showing relationships between airflow and resistance is given in Figure A.2. Factors that must be considered in the selection of a blower are the operating altitude above sea level, operating temperature, static pressure and airflow to be handled. There are different procedures for estimating the cost of a fan system which includes the fan, the motor and the motor starter. In estimating the cost per blower (1973 dollars) the following equation was used in reference IIA-3:

$$\text{Cost } (\$) = 15.341\text{x}(\text{flow rate-cfm})^{0.68}$$

Another procedure for estimating the cost per fan (including motor and starter) is given in reference IIA-4.

The dampers are the valves of the HEPA system. They permit control of pressure, direction, or volume of airflow in the air cleaning system. Some of the factors that must be considered in the selection of dampers are the function of the damper, type of construction, dimensions and space limitations, pressure drop and permissible leakage across the closed damper, normal blade operating position, and operator type and power source. Figure A.3 gives damper purchase price as a function of diameter. Usually 20% of the purchase price is required for installation. Another cost versus damper diameter curve for circular dampers is presented in Figure A.4.

The ductwork is required to provide the desired air distribution, ventilation rates, transport velocities, and other functional requirements of an air cleaning system. The duct costs are influenced by, among other factors, airtightness requirement, system flow characteristics (e.g., flow velocities), space limitations, maintenance of other HEPA system components, and chemical characteristics of the stream. Cost per linear foot of stainless steel (SS) and carbon steel (CS) straight ducts as a function of the duct diameter can be obtained

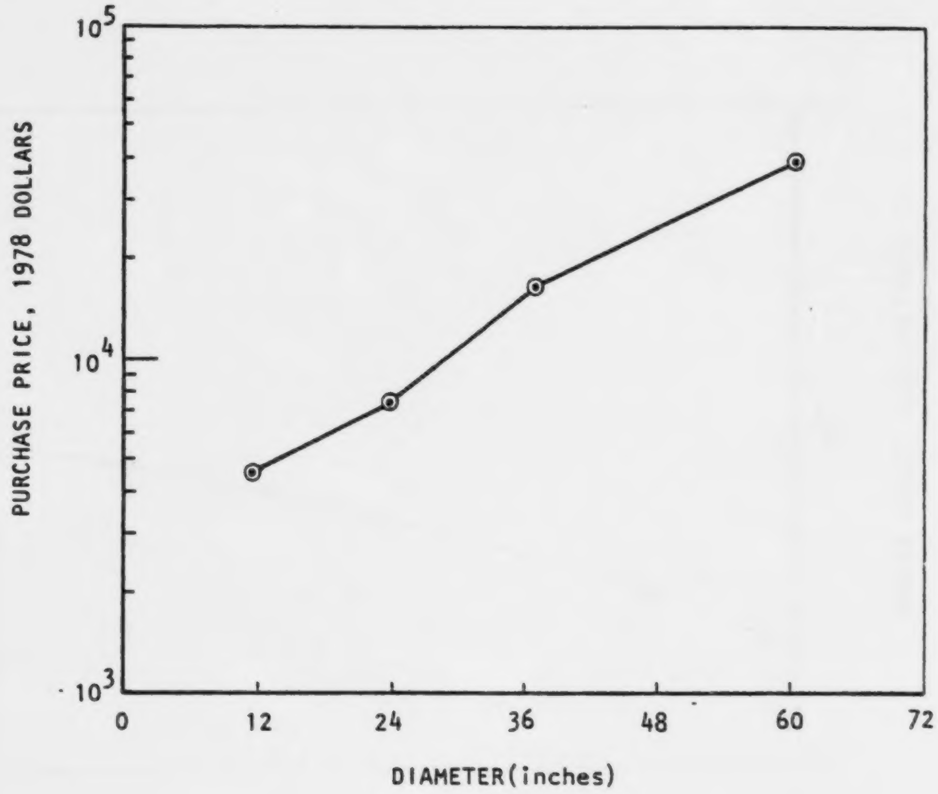


FAN AND SYSTEM CHARACTERISTIC CURVES SHOWING RELATIONSHIPS BETWEEN AIRFLOW DELIVERY AND RESISTANCE. WITH NO DAMPERS TO ADJUST SYSTEM RESISTANCE, AIRFLOW DROPS FROM 14,000cfm, WHEN NEW FILTERS ARE INSTALLED (INTERSECTION OF CURVES A AND 1, $\Delta p = 3$ in.wg) TO 10,000 cfm WHEN THEY ARE REPLACED AT AN ECONOMIC FILTER RESISTANCE INCREASE OF 4 in.wg (INTERSECTION OF CURVES A AND 2, SYSTEM $\Delta p = 7$ in.wg)

# HEPA FILTER VS SYSTEM CHARACTERISTICS

Source: Reference A-2

FIGURE A.2



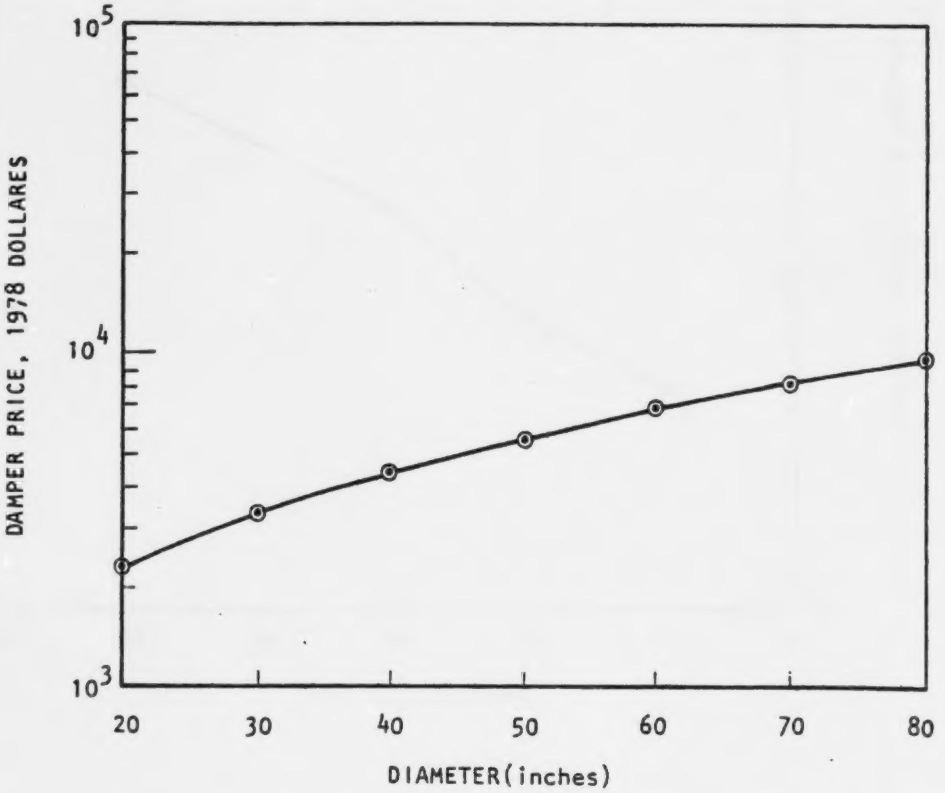
## PURCHASE PRICE OF DAMPERS AND DRIVES

AS A FUNCTION OF DAMPER DIAMETER

SOURCE :
REFERENCE A-3

DAMES & MOORE

FIGURE A.3



DAMPER PRICES VS DIAMETER

CARBON STEEL CIRCULAR DAMPERS WITH AUTOMATIC CONTROLS; FOR STAINLESS STEEL DAMPERS MULTIPLY BY 3.0

SOURCE :
REFERENCE A-4

DAMES & MOORE

FIGURE A.4

from the following equations (IIA-4):

(1/2" thick-SS): Cost($/ft) = -52.1 + 13.7x(diameter-inches)
(1/4" thick-SS): Cost($/ft) = -25.4 + 7.14x(diameter-inches)
(1/2" thick-CS): Cost($/ft) = -4.0 + 3.11x(diameter-inches)
(1/4" thick-CS): Cost($/ft) = -2.12 + 1.83x(diameter-inches)

Another equation used in reference IIA-3 for 14-gauge stainless steel duct costs is given below:

Cost($)/ft = 48.12x(diameter-ft)

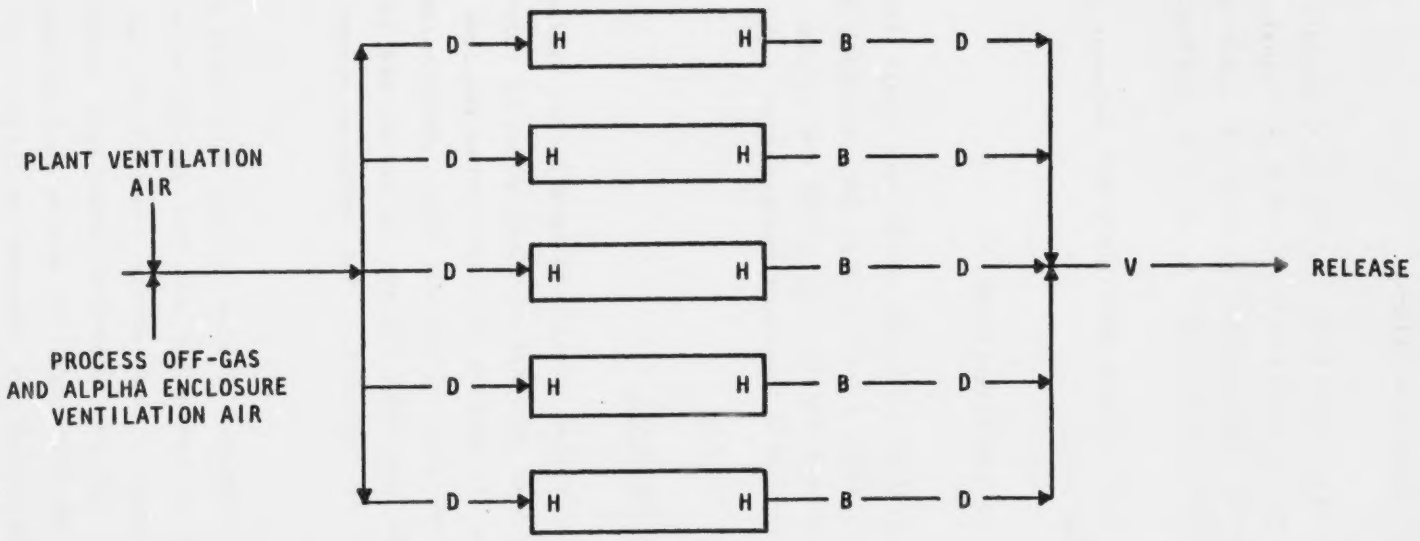
The overall system structure costs can range from very little for a single HEPA filter, to very large for multibank modular systems that require a separate building to house the system. If a special building is required, then standard construction costs for buildings are applicable.

## Sample HEPA System and Costs

The sample HEPA system considered here is the system designed for an LWR mixed-oxide fuel fabrication plant given in reference IIA-3 as Case 1 (see Chapter II, Section 2). The system requires processing of a stream with a flow rate of 120,000 cfm. Decontamination requirements indicate that two HEPA filters in series are needed, and DOP testing capability is required. The designed system is shown in Figure A.5.

The system is composed of five modules each rated at 30,000 cfm, with four modules in operation and one module on standby and/or undergoing maintenance. Each module consists of two dampers, one 40,000 cfm blower, and two in-series banks each containing 30 HEPA filters each rated at 1000 cfm. The system cost is considered in two parts: capital costs, which are composed of direct costs and indirect

H = HEPA FILTERS (10 MODULES OF 30 2ft x 2ft FILTERS)
B = BLOWER (40000 cfm)
D = DAMPER AND DRIVE (43 in.DIAMETER)
V = ISOLATION VALVE (NOT COSTED)


PLANT VENTILATION AIR
PROCESS OFF-GAS AND ALPLHA ENCLOSURE VENTILATION AIR
D
H
H
B
D
V
RELEASE

SAMPLE HEPA FILTER SYSTEM

SOURCE :
REFERENCE A-3.

DAMES & MOORE

FIGURE A.5

costs; and annual costs, which are composed of annual fixed charges and annual operating and maintenance costs.

### Capital Costs

The direct cost portion of capital costs is composed of the costs of the filters, blowers, dampers, ductwork, system structure, and installation. There are a total of 300 HEPA filters, 10 dampers, 5 blowers (with motor and starter), and 500 feet of ductwork in the sample system described above.

Installed cost of each HEPA filter (including bank structure and module housings) has been estimated to be $2200* (IIA-3). This implies a total filter cost of $660,000.

Each damper must handle 30,000 cfm at a rated flow of 3000 fpm. This means that the cross sectional area of the dampers is 10 $ft^2$ which corresponds to a diameter of 3.6 ft (43 inches). The purchase price of the damper has been estimated to be $22,000* (see Figure A.3). Installation costs add another 20% to the cost yielding $26,400 per damper. This implies a total damper cost of $264,000.

Each blower cost (rated at 40,000 cfm), including motor and starter was estimated to be $30,300* (IIA-3). This implies a total cost of $151,500.

The estimated system ductwork was 500 feet of 14-gauge stainless steel ducts. Straight or elboe ducts were not specified. Unit cost for this type of duct has been estimated to be $254* per feet.(IIA-3) This implies a total cost of $127,000.

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* Unit costs given in reference IIA-3 (1973 costs) were multiplied by a factor of 1.467 based upon the Consumer Price Index Listing in order to obtain 1978 costs.

The entire system will require an estimated 70 ft by 80 ft Class I building including services and auxiliaries (IIA-3). Unit cost for this building has been estimated to be \$80.7 per $ft^2$ (IIA-3). This implies a total cost of about \$452,000.

| Item | Direct Cost (1978 dollars) |
|---|---|
| HEPA Filters | \$ 660,000 |
| Damper and Drivers | 264,000 |
| Blowers | 151,500 |
| Ductwork | 127,000 |
| Structure | 452,000 |
| Total : | \$1,654,500 |

Indirect costs result from various items associated with the installation/construction of the air cleaning system. They can be estimated as a percentage of direct cost as follows (IIA-3):

| Item | Percentage of Direct Cost |
|---|---|
| Engineering and Supervision | 15 |
| Construction Expense and Contractor's Fee | 20 |
| Engineering Design (A-E) | 15 |
| Contingency* | 45 |
| Other Owner's Cost | 10 |
| Interest* | 35 |
| Total : | 140 |

This implies an indirect cost for the sample system of about \$2,316,300, yielding a total capital cost of about \$3,971,000.

---

* The contingency allowance and interest during construction has been included as indirect costs to simplify the calculation. Interest is assumed applicable to the cumulative total cost at a rate of 8% per year over a 5 year cash flow expenditure period.

## Annual Costs

The first part of the annual cost, annual fixed charge, results from the invested capital. This charge was estimated to be 24% of the total capital cost based on the following parameters (IIA-3):

| | |
|---|---|
| Plant Lifetime | 15 years |
| Capital Investment in Bonds | 30 % |
| Capital Investment in Equity | 70 % |
| Interest Rate on Bonds | 5 % |
| After Taxes Rate of Return on Equity | 16 % |
| Federal Income Tax Rate | 50 % |
| State Income Tax Rate | 3 % |
| Local Property Tax Rate | 3.2% |
| Annual Cost of Replacements | 0.35% |
| Annual Property Insurance Rate | 0.25% |

However, the current interest rate on bonds is higher that the 5% assumed. This indicated an increase in the annual fixed charge to 26% (IIA-3), and based on this rate, annual fixed charge for the sample HEPA system is calculated to be $1,032,500.

Annual operating and maintenance costs are composed of several items: maintenance cost, blower power cost, DOP testing cost, and filter replacement cost.

Maintenance cost (excluding ductwork, since little maintenance is required for ducts) has been estimated to be 3% of the direct cost (IIA-3), or about $50,000. Blower power cost has been estimated to be $23,000*.

---

* The costs given in reference IIA-3 (1973 costs) were multiplied by a factor of 1.467 based upon the Consumer Price Index Listing in order to obtain 1978 costs.

In-place DOP testing is assumed to require about 2 man-hours of labor, including set-up time per filter bank (IIA-3). Assuming a cost rate of $25 per man-hour and a testing frequency of two tests per year per filter bank, a cost of $1000 is calculated. The HEPA filters are assumed to be replaced every two years. Assuming a cost of $120 per 1000 cfm HEPA filter and labor costs (including other materials) of $25 per man-hour, and using an estimated 32 man-hours (IIA-3) labor required to change a bank of 50 HEPA filters, filter replacement costs are calculated to be about $18,000.

This implies a total annual cost given below:

| Item | Cost ($ 1978) |
|---|---|
| Annual Fixed Charge | $1,032,500 |
| Maintenance | 50,000 |
| Blower Power | 23,000 |
| DOP Testing | 1,000 |
| Filter Replacement | 18,400 |
| Total : | $1,124,900 |

## Sample HEPA Specification

In determining the HEPA filter applicable for a particular system several basic requirements must be specified. These requirements must consider the overall system as well as the HEPA characteristics. One such "equipment specification" is given in reference IIA-1, and is duplicated on the following pages.

# EQUIPMENT SPECIFICATION ES-1

## HEPA FILTER

### 1. SCOPE

This specification covers basic requirements for HEPA (high efficiency particulate air) filters for use in supply-air, contaminated exhaust, contaminated air-cleanup, and other nuclear and hazardous air-cleaning applications requiring extremely high arresting efficiency for all sizes, including submicron, of particulate matter.

### 2. CLASSIFICATION

HEPA filters are classified by size and construction in accordance with Tables 1 and 2.

Table 1. Standard Filter Sizes

| Size | Nominal Airflow Capacity (scfm) | Face Dimensions (in.) | Depth (in.) |
|---|---|---|---|
| 1 | 25 | 8 x 8 | 3-1/16 |
| 2 | 50 | 8 x 8 | 5-7/8 |
| 3 | 125 | 12 x 12 | 5-7/8 |
| 4 | 500 | 24 x 24 | 5-7/8 |
| 5 | 1000 | 24 x 24 | 11-1/2 |

Table 2. Standard Filter Constructions

| Group | Type | Frame Material | Separator Material |
|---|---|---|---|
| 1 | I-A | Cadmium-plated carbon steel | Made without separators |
| | I-B | Cadmium-plated carbon steel | Aluminum |
| | I-C | Cadmium-plated carbon steel | Water-proof asbestos |
| | I-D | Cadmium-plated carbon steel | Corrosion-resistant |
| | II-A | Chromized steel | Made without separators |
| | II-B | Chromized steel | Aluminum |
| | II-C | Chromized steel | Water-proof asbestos |
| | II-D | Chromized steel | Corrosion-resistant |
| 2 | III-A | Plywood, Exterior Grade | Made without separators |
| | III-B | Plywood, Exterior Grade | Aluminum |
| | III-C | Plywood, Exterior Grade | Water-proof asbestos |
| | III-D | Plywood, Exterior Grade | Corrosion-resistant |
| | IV-A | Wood Ptcl. Board, Ext. Gr. | Made without separators |
| | IV-B | Wood Ptcl. Board, Ext. Gr. | Aluminum |
| | IV-C | Wood Ptcl. Board, Ext. Gr. | Water-proof asbestos |
| | IV-D | Wood Ptcl. Board, Ext. Gr. | Corrosion-resistant |

## 3. REFERENCE DOCUMENTS

The following documents are a part of this specification to the extent specified in the text. The issue of one of these documents in effect on the date of the invitation to bid, including any amendments or other published changes in effect on that date, shall apply. If the specification appears to conflict with the requirements of a referenced document, such conflict shall be brought to the attention of the purchaser for resolution.

3.1 Military Specifications and Standards.

| | |
|---|---|
| MIL-S-46055 | *Steel, Sheet and Strip, Low Carbon, Chromized* |
| MIL-F-51068 | *Filter, Particulate, High-Efficiency, Fire-Resistant* |
| MIL-F-51079 | *Filter Medium, Fire-Resistant, High-Efficiency* |
| MIL-STD-282 | *Filter Units, Protective Clothing, Gas-Mask Components, and Related Products, Performance Test Methods* |

3.2 ERDA Health & Safety Bulletins (Energy Research and Development Administration).

*Filter Unit Inspection and Testing Service* (issued annually, number changes with each issue).

3.3 ASTM Standards (American Society for Testing and Materials).

| | |
|---|---|
| ASTM A 165 | *Electrodeposited Coatings of Cadmium on Steel* |
| ASTM A 366 | *Cold-Rolled Carbon Steel Sheets, Commercial Quality* |
| ASTM D 905 | *Strength Properties of Adhesive Bonds in Shear by Compressive Loading* |
| ASTM D 1056 | *Sponge and Expanded Cellular Rubber Products* |
| ASTM E 84 | *Surface Burning Characteristics of Building Materials* |

3.4 TAPPI Standards (Technical Association of the Pulp and Paper Industry)

| | |
|---|---|
| TAPPI T404 | *Tensile Breaking Strength of Paper and Paperboard* |
| TAPPI T411 | *Test for Thickness and Density of Paper* |
| TAPPI T413 | *Ash in Paper* |

3.5 NBS Standards (National Bureau of Standards).

| | |
|---|---|
| NBS PS-1 | *Product Standard for Softwood Plywood, Commercial and Industrial* |
| NBS CS-236 | *Commercial Standard for Mat-Formed Wood Particleboard* |

3.6 UL Standards (Underwriters' Laboratories)

| | |
|---|---|
| UL-586 | *Safety Standard for High-Efficiency Air Filter Units* |
| UL-900 | *Safety Standards for Air Filter Units* |

3.7 IES Standards (Institute of Environmental Sciences, formerly American Association for Contamination Control).

| | |
|---|---|
| CS-1 | *Standard for HEPA Filters* |

## 4. TECHNICAL REQUIREMENTS

4.1 Performance. Filters shall have a maximum penetration of 0.03% (i.e., a minimum efficiency of 99.97%) when tested with monodisperse dioctylphthalate (DOP) smoke having a light-scattering mean droplet diameter of 0.3 micron when operated at rated airflow capacity and at 20% of rated airflow capacity. Maximum clean-filter pressure drop (resistance) across the filter when operated at rated airflow capacity shall be 1.0 inch of water.

4.2 Materials

4.2.1 Filter Medium: glass or glass and asbestos fiber paper having the following properties:

a. DOP Penetration: 0.03% maximum when tested in accordance with Method 502.1.1 of MIL-STD-282.

b. Airflow Resistance: 40 mm water max., when tested at 32 liters/min./sq.ft. of medium, in accordance with Method 402.1.1 of MIL-STD-282.

c. Thickness: 0.15 inch minimum, when tested in accordance with TAPPI T411.

d. Basis Weight (density): 48 lbs per 3000 sq. ft. when tested in accordance with TAPPI T411.

e. Tensile Strength: 2.5 lb/inch width, minimum, in both machine and cross-machine direction, when tested in accordance with TAPPI T404.

f. Elongation: 1.0% minimum at rupture in both machine and cross-machine direction, when tested in accordance with TAPPI T404.

g. Wet Tensile Strength: 1.25 lb/inch width, minimum, when tested in accordance with TAPPI T404 after soaking in water for 15 minutes.

h. Water repellency: 0 penetration of medium under 30-inch head of water when tested in accordance with Method 603.1 of MIL-STD-282.

i. Folding Characteristics: medium shall show no tears, breaks, or cracks when a specimen, cut in the machine direction, is bent 180° around a 1/16-in. diameter mandrel. Folded tensile = 50% original tensile, minimum.

j. Combustible Content: 5.0% maximum when tested in accordance with TAPPI T413.

k. Tensile Strength After Irradiation: not less than 1.0 lb per in. of width in both the machine and cross direction when tested in accordance with e., above, after exposure to an integrated gamma radiation dose of $6.4 \times 10^7$ rad.

l. Water Repellency After Irradiation: 0 penetration of medium under 6 in. head of water when tested in accordance with h., above, after exposure to an integrated gamma radiation dose of $6.4 \times 10^7$ rad.

4.2.2 Case Materials:

a. Type I case: No. 14 US gage carbon steel, ASTM A366.

b. Type II case: No. 14 US gage chromized steel, MIL-S-46055, Type I.

c. Type III case: 3/4-inch fire-retardant treated Grade A-A exterior plywood in accordance with PS-1, having a flame-spread classification of 25 or less when tested in accordance with ASTM E84.

d. Type IV case: 3/4-inch phenolic-resin-bonded exterior wood particle board, batch-treated for fire retardance before forming, in accordance with CS-236 except minimum density shall be 45 lb/cu ft; filled both sides, flame-spread classification of 25 or less when tested in accordance with ASTM E84.

4.2.3 Separator Materials shall meet the following requirements.

a. Type B Separators: aluminum alloy 3003-H19 or 5052-H39, 0.0015 inch thick minimum.

b. Type C Separators: asbestos paper, 4 lb/100 sq ft minimum density, containing no more than 5% combustible materials, qualified in accordance with Appendix A.

c. Type D Separators: asbestos paper, same as Type C, TFE-plastic coated aluminum, or other non-flammable material, qualified in accordance with Appendix B.

4.2.4 Sealants and Adhesives. Sealants used to seal the filter pack into the frame shall have a minimum shear value of 100 psi at $225^{\circ}F$ wood (maple or birch) to wood when tested in accordance with ASTM D 905 under a compression loading rate of 0.1 to 0.2 inch per minute. Adhesives used to glue the gaskets to the frame shall have a minimum peel strength of 10 lb per inch at room temperature, metal surface to neoprene surface. All sealants and adhesives shall be oil resistant and self-extinguishing after exposure to open flame.

4.2.5 Gasket Material shall be oil-resistant, ozone resistant, closed cell neoprene sponge, ASTM D 1056, Grade SCE-43, 1/4 inch thick by 5/8 to 3/4 inch wide (+ 1/8 inch, - 0 inch), with cut surfaces on both faces.

4.2.6 Face Guards, when specified, shall be 4 x 4 mesh galvanized hardware cloth, expanded-and-flattened expanded metal with maximum openings of 1 x 1/2 inch, or perforated metal having maximum openings of 1/2 x 1/2 inch. Pressure drop of filters with face guards shall not exceed the requirements of 4.1.

### 4.3 Construction.

4.3.1 Filters shall be Grade 1 (fire resistant) construction in accordance with Section 6 of IES CS-1, and shall meet the construction requirements of Section 8 of that standard. Case and separator materials shall be as specified by the purchaser; separatorless construction shall be furnished only when specified by the purchaser.

4.3.2 The filter pack of a size 1 or 2 filter shall contain no splices. The filter pack of a size 3 filter may contain one splice. The filter pack of a size 4 or 5 filter shall contain no more than three splices. Splicing shall be in accordance with Section 8.3(1) of AACC CS-1.

4.3.3 Filter media shall not be spot-patched to repair holes or tears, but may be repaired in accordance with Section 8.e.(3) of AACC CS-1.

4.3.4 Edges of separators (except Type A construction) shall extend at least 1/8 inch beyond the pleats and no closer than 3/16 inch to the plane of the face of the frame. Pleats and separators shall not be kinked more than 1/4 inch from a straight line drawn from end to end of the pleat, and shall be perpendicular to the frame with ± 3/8 inch as measured from a perpendicular to the frame drawn from the opposite end of the pleat. The filter core shall be tight when tested as specified in Section 5.3.2.

4.3.5 Group 1 (metal cased) Filters:

a. At least the top and bottom case panels of each filter shall have a 3/8-inch to 1/2-inch flange on the inside, front and back, to restrain movement of the filter pack after assembly of the filter. Case shall have a double-turned 3/4-inch-wide flange on each face. (See Fig. 1.)

b. Individual case panels for Type I construction shall be cadmium plated after completion of all shearing, forming, and spot-welding operations, but before assembly into a complete case. Plating shall be Type OS or heavier, in accordance with ASTM A165.

c. Cases may be assembled with stainless steel, cadmium plated, nickel plated, or chromium plated rivets, bolts, screws, or drive screws. Joint surfaces of individual panels shall be thoroughly coated with adhesive before assembly into the case to ensure a leak-tight corner joint, and assembled case shall meet the dimensional tolerances of 8.b and 8.c of AACC CS-1. Contact areas between the case and the filter pack shall be thoroughly coated with adhesive (sealant) before assembly to ensure a leak-tight assembly.

4.3.6 Group 2 (wood cased) Filters:

a. Cases shall have single-rabbeted corners as shown in Fig. 2 and shall be assembled by double-nailing or double screwing with coated box nails or galvanized flat-head wood screws. Points of fasteners shall not penetrate any surface of the case. Joint surfaces shall be thoroughly coated with adhesive before assembly to ensure a leak-tight joint. Contact areas with the top, sides, and bottom of the filter core shall be coated with adhesive to minimize any possibility of edge-to-edge leakage through the frame.

b. Cases of Type III (plywood case) filters shall be assembled with the Grade A surface of the plywood on the inside, adjacent to the filter core. Any defects in the outer (Grade B) surface shall be coated with adhesive to prevent leakage through the panel.

4.3.7 Dimensional and Assembly Tolerances:

a. Face Dimensions: Less than 24 inches: + 0, —1/16 in.
24 inches and over: + 0, —1/8 in.

b. Depth: + 1/16 in., —0.

c. Squareness: Face diagonals of both faces of Sizes 1, 2, and 3 filters shall be equal within 1/16 inch total allowance; face diagonals of both faces of larger filters shall be equal within 1/8 inch total allowance.

d. Faces: Gasket seating surfaces shall be square with the sides of the frame within ± 3 degrees, and shall be flat and parallel within 1/16 inch total allowance when measured with one face of the filter resting on a surface plate. Sides of the assembled case shall not bow inward or outward more than 1/16 in. in 12 inches, measured on the outside of the case.

4.4 Gaskets. Filters shall have a gasket on one face only unless otherwise specified by the purchaser. Gaskets shall be made from strips of neoprene cemented evenly to the flange surface with a rubber-base adhesive; the surface of the flange surface shall be cleaned with a degreasing solvent (fluorocarbon, trichloroethylene, acetone, etc.) before cementing the gasket. Gasket strips shall have keyhole or dovetail joints at the corners and shall not be spliced between the corners; edges of the joint surfaces shall be coated with adhesive during assembly to ensure a leak-tight joint. There shall be no evidence of adhesive, cohesive, or contact failure in the joint between the gasket and the flange face. After curing of the adhesive gaskets shall have a minimum peeling strength of 10 lb per inch of width.

4.5 Face Guards. Size 4 and 5 filters shall have face guards installed on both faces unless otherwise specified by the purchaser. Face guards shall be firmly embedded all around, with no projecting wires or edges that might penetrate the filter medium or be safety hazards to personnel handling the filters.

4.6 Marking. Each filter shall be marked on the top panel with the following information; marking shall be oriented to read from the downstream side, relative to the position of the filter during test (Section 4). Marking shall be by indentation-stamping or indelible ink; ink characters shall be at least 1/4 inch high and shall be clear and distinct; variable data (penetration and pressure drop values) may be handwritten; serial number shall be printed. Marking shall not be furnished on a paper label. Marking shall include the following information:

Manufacturer's name or symbol
Percent penetration, actual, at rated capacity (all sizes)
Percent penetration, actual, at 20% of rated capacity (Sizes 4 and 5 only)
Filter serial number
Airflow capacity, cfm
Pressure drop at rated capacity (all sizes)
Pressure drop at 20% of rated capacity (Sizes 4 and 5)

## 5. QUALITY ASSURANCE REQUIREMENTS

5.1 Quality Assurance Plan. Filters shall be manufactured under the surveillance of a formal quality assurance program, in accordance with formalized and documented manufacturing and quality assurance plans. Quality assurance personnel shall not report to the production manage of the manufacturer's plant.

5.2 Qualification. The filter design, construction, and medium shall be qualified in accordance with the following requirements. Qualification tests shall be made by the manufacturer, a qualified testing laboratory mutually acceptable to the manufacturer and the purchaser, or by the U. S. Army. Listing of the item in a Military Qualified Products List shall be objective evidence that the product meets the qualification requirements. Once qualified, a given filter design need not be requalified for subsequent shipments to this or other pruchasers unless there has been a change in design, method of manufacturer, or materials, except each manufacturing lot of filter medium shall be tested as specified below.

5.2.1 Filter Medium. Each manufacturing lot of filter medium shall be tested in accordance with the requirements of MIL-F-51079 except with the following modifications: (NOTE: paragraph numbers in text of requirements below refer to the paragraph numbers of MIL-F-51079):

a. Tensile Strength and Elongation. Twenty machine-die-cut specimens, each 1 inch x 6 inches in length, 10 having the long dimension parallel to the machine direction and 10 having the long dimension parallel to the cross direction, shall be conditioned and tested for tensile strength and elongation in accordance with TAPPI T404, using a motorized Instron University Testing Machine at a loading rate of 0.5 inch per minute, or at a loading rate which will complete the test in 10 ± 2 seconds, whichever is greater.

b. Tensile Strength After Heated Air. Delete in its entirety.

c. Wet Tensile Strength. Ten test specimens, each 1 inch x 6 inches, five having the long dimension parallel to the machine direction and five having the long dimension parallel to the cross direction, shall be submerged in water at a depth of at least 10 inches for at least 15 minutes, and then tested for wet tensil strength as specified in 4.2.4.2(a). The average of the test results shall be considered the wet tensile strength of the medium.

d. Water Repellency. Three test specimens, each 2-3/4 inches x 5-1/2 inches, shall be tested for water repellency using the Q101 Water Repellency Indicator (DLB-125-8-1). Each specimen shall be cut into two equal size squares. The felt (top) side of one square and the wire (bottom) side of the other square shall be tested; the lesser of the two results shall be considered the water repellency of the specimen. The minimum water repellency of the three specimens shall be considered the water repellency of the medium.

e. Mildew Resistance. When specified in the Ordering Data, mildew resistance tests of the medium shall be conducted in accordance with method 5750 of FED TEST METHOD 191.

f. Acidity. Delete in its entirety.

g. Thickness. The thickness of the medium shall be determined in accordance with TAPPI standard T411, using a TMI No. 549-M Thickness Tester with 5/8 inch diameter anvils.

h. Combustibles Content. The dried weight of the sample shall be recorded. The ash weight shall be determined in accordance with TAPPI standard T413, except the sample shall be either heated for 2 hours at 800°C or for minutes at 1000°C. Percent combustible content shall be determined from the equation:

$$\text{Percent Combustible} = \frac{\text{Sample weight} - \text{Ash weight}}{\text{Sample weight}} \times 100$$

i. Radiation Resistance. Radiation resistance of the medium shall be determined as follows: Twenty 1-inch x 6-inch tensile-test specimens (10 with the long dimension parallel to the machine direction and 10 with the long dimension parallel to the cross direction) and three 2 3/4 x 5 1/2 inch water repellency specimens shall be subjected to gamma radiation. Irradiated tensile test specimens shall be tested in accordance with 4.2.4.2(a). Irradiated water repellency specimens shall be tested in accordance with 4.2.4.3.

5.2.2 Filter Design and Materials. Filter design and materials of construction shall be tested for qualification as follows:

a. Resistance to Fire and Hot Air. Each filter design and combination of materials of construction shall be tested for qualification in accordance with UL-586 or the requirements for heated-air and spot-flame resistance of MIL-F-51068. Presence of the Underwriters' Laboratories label certifying compliance with UL-586, or listing of the design in a military Qualified Products List, shall be satisfactory evidence of compliance with this requirement.

b. Resistance to Moisture and Overpressure. Each filter design and combination of materials of construction shall be tested for qualification as follows:

> Operating at rated capacity, the test filters (at least four of the design to be qualified) shall withstand a load of water spray that will produce a pressure differential across the filter core of 10 in. water guage for one hour without permanent damage, as determined by testing, after the filter is dried, in accordance with 5.3. The filter, when tested after drying, shall meet the requirements of 4.1 and the dimensional requirements of 4.3.6-a, b, and c.

Listing of the design in a military Qualified Products List shall be satisfactory evidence of compliance with this requirement.

c. Resistance to Rough Handling. Each filter design and combination of materials of construction shall be tested for qualification as follows:

> The test filters (at least two of the size and design to be qualified) shall withstand rough handling in accordance with Method 105.9 of MIL-STD-282 for 15 min. at 3/4 in. total amplitude and a frequency of 200 Hz, with pleats and filter faces in a vertical orientation, without visible damage or loss of filtration efficiency, as determined by testing in accordance with 4.3.1. After rough handling, the filters shall meet the requirements of 4.1 and 4.3.6-a, b, and c.

Listing of the design in a military Qualified Products List shall be satisfactory evidence of compliance with this requirement.

5.2.3 Separator Materials. Asbestos separator material shall be qualified in accordance with Appendix B of this specification. Corrosion-resistant separator material shall be qualified in accordance with Appendix C of this specification. Test results of qualification tests shall be made available to the purchaser on request.

5.3 Production Lot Testing.

5.3.1 Performance Test. Each filter element shall be individually tested for DOP penetration and airflow resistance in accordance with Method 102.9.1 of MIL-STD-282 except: (1) the Q-107 or Q-76 filter testing penetrometer shall be modified to permit the complete filter element to be encapsulated during test in order to establish the presence of frame leaks; (2) tests shall be conducted with the filter element encapsulated; (3) tests shall be made and reported at 100% of rated capacity and also, for filters larger than 125 cfm rated capacity, at 20% of rated capacity. The results of tests shall be marked on the case of the filter element; test reports are not required unless expressly specified by the purchaser, and shall comply with the requirements of 4.1. Filters which fail this test shall be rejected.

5.3.2 Core-Tightness Test. A test shall be made of the tightness of the filter core. The test may be made on a number of filters corresponding to at least 5% of the number of filters in the shipment, but no fewer than 5 filter elements. The test is made as follows:

> Lay filter face down on a flat surface. Place a 4-x-6-inch block of wood, covered with a neoprene pad glued to one surface, at the center of the filter face. Place a 4-lb weight on the block. A force of 4 lbs exerted on the block in a direction parallel to the face of the filter and perpendicular to the pleats shall cause the block to move no more than 1/16 inch from its original position in either direction.

Failure to meet the requirements of this test shall be cause for rejection of the shipment.

5.4 Tests By ERDA Quality Assurance Station. When specified by the purchaser, filters shall be shipped to one of the ERDA Quality Assurance Stations in accordance with instructions contained in the current issue of the ERDA *Health and Safety Bulletin* on Filter Unit Inspection and Testing. The Quality Assurance Station shall inspect each filter to verify that it complies with this specification and that it is free of visible damage, evidence of poor workmanship, and errors in manufacture, and shall test the filters in accordance with 5.3 above. The Quality Assurance Station shall then repack the filters in the manner in which they were shipped, to them, and ship them to the specified delivery site in accordance with the purchaser's instructions. Acceptance of filters shall be at the Quality Assurance Station upon successful completion of the requirements of this section.

## 6. PREPARATION FOR DELIVERY

6.1 Filter Packaging. Filters shall be individually packaged or packed with individual corrugated paperboard separators in wood or corrugated paperboard cartons having corner braces, inserts, or other means of shock prevention to protect the filters from damage during handling, shipping, and storage. Size 4 and 5 filters shall be enclosed within a corrugated paperboard sleeve having integral spacers to hold the filter, while in the carton, at least 1 inch from all walls of the carton (separate spacers may be used at the top and bottom of the filters), or be protected with plywood or heavy-paperboard on each face, with spacers to hold the filter, while in the carton, at least 1 inch from all walls of the carton.

6.1.1 Filters shall be placed in the carton so that the faces and the pleats are vertical when the carton is in its normal shipping orientation. Cartons shall be marked FRAGILE - HANDLE WITH CARE and THIS SIDE UP, or similar legends, in black or red heavy block characters at least 3/4 inch high.

6.1.2 Packing and packaging shall be of a type, weight, thickness and material which is acceptable to the public carrier in compliance with Uniform Freight Classification Rules, the National Motor Freight Classification Rules, or other applicable freight classification rules.

6.2 Shipping.

6.2.1 Loading in Public Carriers. Cartons shall be banded to skids so that the specified filter orientation is maintained during shipment, or packed in the carrier's truck or railroad car so that the specified filter orientation is maintained. Cartons shall not be stacked more than 6-1/2 ft high unless a platform is provided to support the tiers of cartons above the 6-1/2 ft height, and other materials shall not be stacked on top of the filter cartons during shipment. A packing list shall be affixed to the outside of one carton of each shipping unit (one skid or pallet load comprises a shipping unit) giving the name of the manufacturer, description of contents, quantity in the order, quality in the shipping unit, indication that the shipment is partial or complete, name of purchaser, and purchaser's order number.

6.2.2 Transhipment. If possible, shipment shall be arranged so that the filters are not disturbed after they leave the manufacturer's plant until they are received at the USERDA Quality Assurance Station, and, after leaving the Quality Assurance Station, until they are received at the delivery site. The common carrier should be instructed that Quality Assurance Station and Purchaser's personnel, respectively, shall be responsible for unloading the truck or railroad car. Railroad cars shall be marked, DO NOT HUMP. The carrier shall report all transshipments to the purchaser.

6.2.3 Sealed Trailer. When specified by the purchaser, filter shall be transported to the delivery site (and to and from the ERDA Quality Assurance Station, when specified) in a sealed trailer or containerized-freight unit. Filters shall be packed and oriented in the trailer or containerized-freight unit as specified in 6.2.1 above.

## 7. PURCHASE DOCUMENT

Purchase documents for filters bought in accordance with this specification shall (1) cite the number and title of this specification; (2) show the size (see Table 1) and type of construction required (see Table 2); (3) specify gaskets on both faces, if required (4.4); (4) specify face guards, if required (4.5); (5) specify shipment to and testing by an ERDA Quality Assurance Station, with address of station, if required (5.4); (6) specify any special packing or packaging requirements (6.1); (7) method of shipment (6.2); and (8) specify any exceptions to the specification.

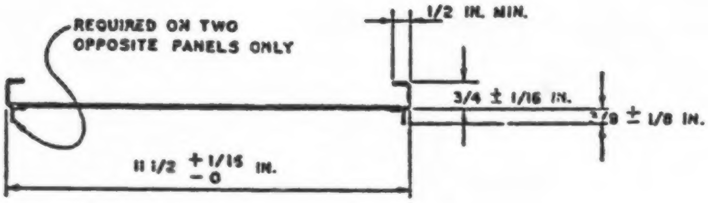
REQUIRED ON TWO OPPOSITE PANELS ONLY
1/2 IN. MIN.
3/4 ± 1/16 IN.
/8 ± 1/8 IN.
11 1/2 +1/15 −0 IN.

Fig. 1. Section through case panel, metal-cased HEPA filter.

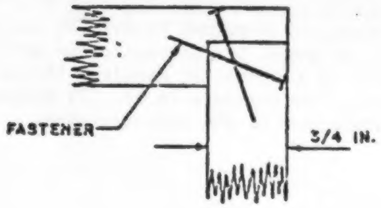
FASTENER
3/4 IN.

Fig. 2 Corner detail, wood-cased HEPA filter.

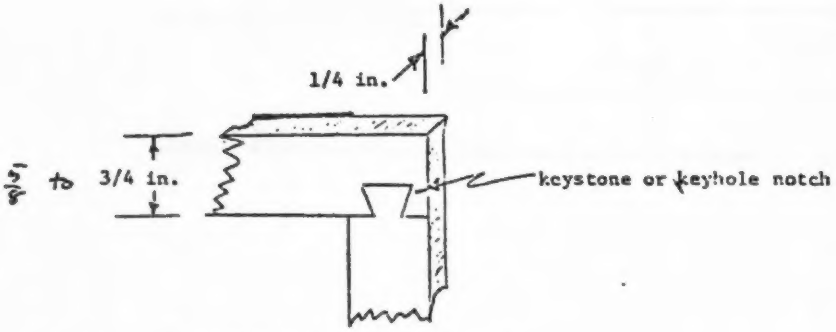
1/4 in.
5/8 to 3/4 in.
keystone or keyhole notch

Fig. 3 Corner detail, flat neoprene gasket.

## APPENDICES

### A. QUALIFICATION TEST FOR MOISTURE RESISTANCE OF SEPARATOR MATERIALS

Ten sections of corrugated separator, each 4 inches long and containing 5 corrugations, shall be immersed in tap water containing 2 to 3 percent by weight trisodium phosphate base detergent for one hour. After soaking, each section, in turn, shall be laid flat and a load of 1/2 lb evenly distributed over the tops of the corrugations, shall be placed on the sample. None of the sample shall flatten, and corrugations shall not decrease in height by more than 50 percent.

### B. QUALIFICATION TEST FOR CORROSION RESISTANCE OF SEPARATOR MATERIALS

1. Equipment Requirements. Taber V-5 Stiffness Tester and Taber Specimen Shear.

2. Preparation of Test Specimens. Cut 33 test specimens from flat stock, using specimen shear, with long dimension of specimen parallel to machine direction of stock. Divide specimens into eleven sets of two specimens per set, and number each specimen with a set identification. Measure the thickness of each specimen at each end and at the center in accordance with TAPPI T411. Record average weight of each specimen.

3. Conditioning. Condition each set of specimens as follows:

Set # 1 Control sample; do not condition.

Set # 2 Soak in 25°C water for 1 hour.

Set # 3 Immerse in 6M $HCl$ for 2 minutes, blot, and soak in 25°C water for 1 hours.

Set # 4 Immerse in 10% HF solution for 1 minute, blot, and soak in 25°C water for 1 hour.

Set # 5 Immerse in 6M $HClO_4$ for 2 minutes, blot, and soak in 25°C water for 1 hour.

Set # 6 Immerse in 9M $H_2SO_4$ for 2 minutes, blot, and soak in 25°C water for 1 hour.

Set # 7 Immerse in 7.5M $HNO_3$ for 2 minutes, blot, and soak in 25°C water for 1 hour.

Set # 8 Immerse in 50% NaOH solution for 2 minutes, blot, and soak in 25°C water for 1 hour.

Set # 9 Steam for 6 hours at approximately atmospheric pressure, blot and soak in 25°C water for 1 hours.

Set #10 Steam for 3 hours at approximately 25 psig, blot, and soak in 25°C water for 1 hour.

Set #11 Heat in furnace at 850°F for 5 minutes cool for 5 minutes, and soak in water for 1 hour.

4. Stiffness Determination. Blot specimen, determine stiffness with Taber V-5 Stiffness Tester while still wet; record stiffner value. Dry specimen and repeat. Average stiffness values for each set; report test values and average-wet-and-dry-stiffness values for each set.

5. Acceptance. Minimum average wet stiffness of any set shall be 10 Taber Stiffness Units. Minimum average dry stiffness of any set shall be 12 Taber Stiffness Units.

## REFERENCES

IIA-1 Burchsted, C.A., Kahn, J.E. and Fuller, A.B., *Nuclear Air Cleaning Handbook,* U.S. Energy Research & Development, ERDA 76-21,1976.

IIA-2 Flanders Filters Inc. *Air Filtration Products Catalog, HEPA Filters & Filter Systems.* Washington, North Carolina, 1979.

IIA-3 Gronier, W.S., et al. *Correlation and Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "as Low as Practicable" Guides - Fabrication of Light-water Reactor Fuels Containing Plutonium.* ORNL-TM-4904, 1975.

IIA-4 *The Fabric Filter Manual. Volumes 1-3.* Northbrook, Illinois: The McIlvaine Company, 1976.

IIA-5 Flanders Filters Inc. Personal communication,* 1979.

* Individual chose to remain anonymous.

# APPENDIX IIB

## Particulate Control Technologies

# APPENDIX II.B

## Introduction

There are three general categories of control technologies used to capture particulate emissions that result from burning fossil fuels at electric generating plants. They are electrostatic precipitators, scrubbers and fabric filters. In the section that follows, each of the technologies is described.

## Electrostatic Precipitators

From a survey of electric power plants taken during the course of this study indications are that electrostatic precipitators are the most widely used control technology in those plants meeting the New Source Performance Standards.

Electrostatic precipitation means electrical collection of particulates suspended in a gas stream. The process depends on the results from the interaction of an electrically charged particle and an electric field. They are used extensively to remove fly ash from flue gas of fossil fuel electric power generators. Operating at mass collection efficiencies of 99+%, they capture large size particles to particles below the 2 um diameter size.

### Description

McIlvaine (IIB-1) provides a description of electrostatic precipitators which is quoted on the following page.*

*Reprinted from the McIlvaine Electrostatic Precipitator Manual by permission of the McIlvaine Co., 1976.

"The precipitator process involves four steps: the electrical charging of the dust particles, [establishment and mainatenance of an] electric field to ['accelerate'] the particles to the collection electrodes, the removal of this collected particulate from the collection electrodes for temporary storage and finally the removal and disposal of this collection material.

Both the charging and collection processes are directly influenced by the electric field in the electrostatic precipitator. The electric field is established in a precipitator by applying a high voltage to the electrode system. The electrode system in the typical single stage industrial electrostatic precipitator consists of a corona ['producing'] and 'discharging electrode'] with a small radius of curvature and a collection or passive electrode with a large radius of curvature. This electrical configuration leads to large electric fields near the corona electrode (20 kilovolts per centimeter) with moderate electric fields in the vicinity of the collection electrode ( 2 kilovolts per centimeter).

In the precipitator process, dust suspended in the gas is electrically charged and passed through an electric field where electrical forces cause the particles to migrate toward the collection surface. The dust is separated from the gas by retention on the collection electrode and subsequently removed from the precipitator. Various physical configurations are used to accomplish these basic functions of charging, collection, and removal, depending upon the type of application and properties of the dust and gas.

Even though particles in a gas stream normally have a small inherent electric charge, this charge is orders of magnitude too small for effective electrostatic collection. Consequently, the precipitation system must provide a means for particle charging.

In all commercial precipitator applications, this charging is accomplished with a high-voltage, direct-current electrical corona.

### Corona Generation

Corona, as applied to electrostatic precipitators, is a gas discharge phenomenon associated with the ionization of gas molecules by electron collisions in regions of high electric field strength. The process of corona generation requires a non-uniform electric field, which is obtained by the use of a small radius of curvature structure as one electrode and a plate or cylinder as the other electrode. The application of a high voltage to this electrode configuration results in a high electric field near the corona electrode with the field strength decreasing with distance from the electrode surfaces.

The corona process is initiated by the presence of free electrons in the high field region. Electrons for corona initiation are supplied from natural radiation or other sources and, since they are in a region of high electric field, they are accelerated to high velocities. These high velocity electrons possess sufficient energy so that on impact with gas molecules they release orbital electrons from the neutral gas molecules. These additional free electrons are also accelerated and enter into the ionization process, termed avalanche.

Within the corona discharge region, where ionization is taking place, there are free electrons and positive ions resulting from free electron impact ionization. The behavior of these charged particles depends upon the polarity of the electrodes; the corona is termed negative corona if the discharge electrode is negative, and positive corona if the discharge electrode is positive. Both positive and negative coronas are used in industrial gas cleaning applications; however, the negative corona is most prevalent within the temperature range of most industrial applications.

In the case of the negative corona, the positive ions generated in the corona region are attracted toward the negative corona electrode and electrons are driven toward the positive plate or cylinder electrode. Beyond the corona glow region, the electric field diminishes rapidly [reducing electron acceleration. Gas molecules will capture electrons to become negative ions.] The negative ions thus generated move toward the collection electrode and serve as the principal means for charging the dust.

In the corona process, there must be a source of electrons to initiate and maintain the avalanche process. The electrons are supplied from naturally occurring ionizing radiation, photoionization due to the presence of the coronas glow, and, in the case of high temperature operations, from thermal ionization at the electrode surface. For negative coronas, electrons are also provided by secondary emission from the impacts between the positive ions and the discharge electrode. Cosmic and terrestrial radiation provide approximately 20 ion-electron pairs per cubic centimeter of gas per second to serve as initiating electrons.

The mobility of the various charge carriers plays an important role in the corona generation process. Electron mobility in high fields is approximately 400 times that for ions. In the negative corona case, the electron mobility is such that sparking would occur when the field required to initiate corona is reached unless the electrons are attached to gas molecules to form a stabilizing space charge.

In most industrial gas cleaning applications, there are sufficient quantities of electronegative* gases, such as oxygen and sulfur dioxide, so that practically all of the electrons are attached to gas molecules. Gases such as nitrogen, helium, argon, etc., do not form negative ions, and hence a stable negative corona is not possible in these gases.

In a positive corona, the electrons generated by the avalanche process flow toward the [discharge] electrode. Since the positive ions are the charge carriers, they serve to provide an effective space charge, and the presence of an electronegative gas is not required for a positive corona.

Positive and negative coronas differ in several important aspects. In appearance, the positive corona is a rather uniform sheath surrounding the discharge electrode, whereas the negative corona appears as localized discharges from points along the electrode. The voltage current characteristics of the negative corona are superior to those of the positive corona at temperatures at which most commercial precipitators operate, since higher operating voltages and currents can be reached prior to disruptive sparking. It is postulated that a spark or arc breakdown in the interelectrode space occurs by formation of a streamer originating at the positive electrode surface. In the positive corona, the origin of the streamer would be at the surface of the discharge wire, and hence in a high field region. In the negative corona, the positive electrode is the collection plate and the field near the surface is considerably less than at the discharge electrode; hence a higher voltage would be required for spark propagation.

The negative corona is accompanied by the generation of larger quantities of ozone than the positive corona, and therefore is not usually used for cleaning air in inhabited space. However, most industrial gas cleaning precipitators utilize a negative corona because of its inherently superior electrical characteristics which lead to increased efficiency when the operating temperatures are favorable.

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*Electronegative i.e., the ability to become negative ions.

Geometry of the electrodes, gas composition, and gas conditions have important influences on corona generation. The diameter of the discharge electrode and the electrode spacing determine the voltage gradient, [or electric field.] The electric field varies as the reciprocal of the radius near a small diameter wire, thus with a very small wire, the electric field near the surface can be quite high, often in the range of 50-100 kV/cm. The avalanche process requires the presence of a high electric field over a given distance. In general, the smaller diameter wire requires a higher electric field strength for initiation of corona. For a given spacing, however, the onset of corona occurs at a lower voltage for the smaller diameter wire. Also, for a given voltage, higher currents are obtained with smaller diameter discharge electrodes.

Temperature and pressure influence the generation of corona by changing the gas density. In the avalanche process, the time available for accelerating an electron between collisions is [partially] a function of gas density. With increased molecular spacing, higher velocities can be achieved between collisions. Thus, ionizing energy can be achieved with lower electric fields for low gas densities.

A second effect, in the case of the negative corona, is that the increased molecular spacing results in the penetration of free electrons further into the interelectrode region before they are captured to form negative ions. This results in an increased average mobility in the interelectrode space, and hence a higher current. Additionally, at very high temperatures (above about 1500°F) thermionic emission increases, further increasing the number of free electrons and the effective average charge mobility.

These effects reduce the voltage required for sparkover, so that at high temperatures the positive corona should give superior voltage-current relationships and improved collection efficiency since electrons move toward the discharge electrode in a positive corona.

### Dust Effects on Corona Generation

Corona generation studies of a basic nature are often made with clean electrodes under laboratory conditions. These conditions are highly idealized in comparison to industrial precipitators. In practical precipitators, the presence of a dust laden gas has several effects on corona generation. First, the dust entering the interelectrode space becomes charged by attachment of negative or positive ions. Because of the much lower electrical mobility of the charged dust, it constitutes a significant space charge. The magnitude of the space charge depends upon the size and quantity of the dust and the magnitude of its charge. The effect of the space charge is to reduce the electric field in the vicinity of the corona glow region and thus it tends to quench the corona and reduce the current. This effect is particularly significant at the inlet section of a precipitator where dust concentrations are highest. Special electrode shapes are often used in an attempt to minimize this space charge problem at the inlet section.

A second important consideration of the effects of dust on corona generation is the deposits formed on both collection and discharge electrodes. On the collection electrode, dust deposits alter the electric field and sparking conditions as a result of the voltage drop within the dust layer. This effect limits the voltage and current at which the precipitator can operate, and its chief influence on corona generation.

Dust deposits also form on the discharge electrode in operating precipitators. This deposit can be quite heavy in the case of some types of dust. The effect on corona can be considerable depending on the nature of the deposit and the electrical properties of the dust. If the dust resistivity is reasonably low, the effect of the deposit will be to effectively increase the diameter of the discharge wire. This results in higner voltage required for corona initiation or reduced corona current for a given voltage. If the dust deposit is uneven, an uneven distribution of corona along the length of the wire may result.

If the dust resistivity is high, the effect generally would be to reduce corona current for a given voltage. However, if the deposit is somewhat porous, breakdown of the gas in the interstitital region can occur and the effect of the deposit may be reduced.

The current in a precipitator is carried by free electrons, ions, and charged dust particles. The magnitude of the current carried by each is related to the number densities and mobility of the carriers, and the electric field. Mobilities are related to the various physical parameters of the charged particle, but primarily to the charge-to-mass ratio of the carrier. Electrons, with their low mass, have the highest mobility of all the current carriers ( 750 $cm^2$/volts sec). Oxygen ions would have a lower mobility, about 1/400 that of an electron ( 1.9 $cm^2$/volts sec), and charged dust particles have the lowest mobility of all the current carriers (in the range of 0.02 $cm^2$/volts sec). These mobilities are for conditions normally encountered in commercial installations.

It is thus apparent that for a given electric field, the current carried by each of the carriers is in proportion to their mobilities for the same number densities. For a negative corona, the number densities of the charged particles change in traversing the glow region from the discharge electrode surface. At the surface, the positive ion density is greatest, since all of the positive ions from the avalanche process flow to the discharge electrode. At the boundary of the corona region, ion generation ceases; hence the concentration of positive ions is essentially zero beyond that point.

The number of free electrons at the corona electrode surface is negligible and increases to a maximum at the boundary of the corona glow region (because of the avalanche process). Moving into the quiescent zone, free electrons are captured by the electronegative gas molecules to form negative ions. The probability of electron capture is high because of the number of electronegative gas molecules present, as a result the electron density rapidly decreases beyond the corona glow boundary.

As the electrons from the corona are captured by the gas molecules, the negative ion concentration increases. Traversing further into the interelectrode space, signficant quantities of the negative ions attach to the dust particles present to form charged particles. The number of free ions then decreases as they are consumed in the particle charging process. A considerable fraction of the negative ions present go to charging the dust particles, although the percentage of the current resulting from bound ions is generally small because of the difference in mobilities.

The currents carried by these various carriers can be determined by their number densities, mobilities, and the electric field strength. It should be remembered, however, that the number densities of the various carriers, as well as current, are important in the analysis of precipitator operation.

## Particle Charging

There are two mechanisms by which gas ions impart charge to dust particles in the precipitator. Dust particles in an electric field cause localized deformation of the field so that electric field lines intersect the particles. Ions present in the field tend to travel in the direction of maximum voltage gradient, which is along electric field lines. Thus, ions will be intercepted by the dust particles, resulting in a flow of charge to the particle. The electrical charge will be held to the dust particle by an induced image charge force between the ion and dust particle. As additional ions collide with and are held by the particle, the particle becomes charged to a value sufficient to divert the electric field lines such that they do not intercept the particle. Under this condition of saturation charge, no ions contact the the dust particle and it receives no further charge. The theory of the process shows that the saturation value of the charge of the particle is related to the magnitude of the electric field in the region where charging takes place, the size and dielectric constant of the particle. The saturation charge is proportional to the square of the particle diameter, thus larger particles are more easily collected than small ones. This mechanism of charging is called field-dependent charging.

The time required for a particle to acquire a saturation charge is an important factor that is often neglected in precipitation theory. If a single particle is introduced into a high ion density region, charging takes place in milliseconds. However, charging times by the field-dependent regime can be appreciable under practical conditions of large dust loading and low electrical current densities.

For small particles, the field dependent charging mechanism is less important, and collision between the particles and gas ions is governed primarily by the thermal motion of the ions. Since the range of thermal velocities has [theoretically] no upper boundary, there is no saturation value associated with diffusion charging. However, as the charge on a particle increases, the probability of impact decreases, so that there is a decreasing charging rate associated with an increasing particle charge. This charging process is called diffusion charging.

In practical precipitators, field-dependent charging is usually of most interest, but in some application, significant quantities of particles are present in the range where diffusion charging is the predominant mode (<0.2 diameter) as well as the area in which both mechanisms are significant.

Particle charging theory indicates several important factors governing precipitator performance. Since the magnitude of the particle charge is dependent upon the magnitude of the electric field in the field-dependent mode, it is important that field strength be kept as high as practical. A second factor of importance is the rate of charging of the particles. Practical precipitators generally introduce heavy concentrations of uncharged dust in the inlet section of the precipitator. Calculations show that the number of ions required to charge this dust to its saturation value may be large, hence the number of free ions present may be substantially reduced and charging times may become appreciable.

The waveform of the applied voltage is significant as it influences the peak value of the electric field. The saturation value of the particle charge is ['partially'] determined by the peak value of the electric field. However, charging only occurs during the interval of time that the applied field exceeds the self-field corresponding to the charge on the particle. Consequently, longer times will be required to reach saturation for a varying voltage than for a pure d-c voltage. However, the varying voltage is sometimes preferable for spark quenching and permits operation at a higher average voltage.

The electric field in a precipitator determines the maximum value of the particle charge resulting from field-dependent charging and also the force acting on a charged particle. Since the electrical field enters the collection efficiency equations effectively as a squared term, it is important that the magnitude of the field be maintained as high as practical.

The electric field strength is determined by the electrostatic component, which is related to the precipitator geometry and the applied voltage; and by the space charge component, which is related to the presence of charged particles, (ions and charged particulate) in the interelectrode space. The design of the precipitator can be varied to alter the geometry of the discharge electrode and the electrode spacing. These factors can determine the magnitude of the electrostatic component.

Variations in electrode geometry can also alter the corona current, which in turn influences the electric field by changing the space charge contribution. Equations describing the electric field for clean electrodes have been developed from classical ['electromagnetic theory (Maxwell's Equations)']. Utilizing these equations, it is possible to predict the field at any location, assuming clean electrodes.

### Dust Resistivity

In a practical precipitator, dust accumulations on the [positive] collection electrodes limit the maximum voltage, and hence the electric field strength at which the precipitator can operate. The voltage drop across the dust layer is dependent upon the corona current density, the electrical resistivity of the dust, and the thickness of the dust deposit. For high resistivity dusts, the voltage drop across the collected dust layer can be significant. Obviously, the electrical energization equipment must be capable of providing sufficient voltage to accomodate this voltage drop, while maintaining adequate voltage across the interelectrode spaces. The effect of the resistivity of the dust layer, however, is more severe than its influence on power supply voltage. The electric field in the dust layer can be quite high for high resistivity dust leading to sparkover at lower applied voltage and current density of the precipitator.

A second condition associated with high dust resistivity can also influence particle charging and the magnitude of the electric field. Once sparking occurs, a crater is formed in the dust layer, and current densities in the localized area can result in localized electric fields that are sufficiently high to initiate a corona emanating from the base of the crater. This corona results in positive ion production and, as a result of the direction of the electric field, these ions will flow toward the discharge electrode. Collisions with dust particles tend to charge them with opposite polarity to that required for collection. Also, collision with negative ions tends to neutralize them, reducing the ion density in the interelectrode space.

If dust resistivity is further increased, a diffuse corona glow may appear over the large areas of the dust surface. Under these conditions the positive ion production by the reverse corona may be sufficient to completely disrupt the charging process, and effective precipitation is not possible under these conditions.

## Efficiency Determination

The forces acting on a charged particle in a precipitator are gravitational, inertial, electrical, and aerodynamic. The latter two are the principal ones of importance in electrostatic precipitation.

If a particle is suspended in a laminar gas flow stream in a pipe and wire precipitator, a force because of the electric field and particulate charge will act on the particle in the direction of the collection electrode. This force is opposed by the viscous drag force of the gas. The particle reaches a terminal velocity at which the electrical and viscous drag forces will be equal. In precipitator terminology, this is called the migration velocity. The other primary [velocity component is that resulting from the] aerodynamic force [of] the gas stream. The motion of the particle will be along the line defined by the vector sum of these two 'velocities'. Under laminar flow, all particles would be collected in a given length of the precipitator and the collection efficiency for shorter lengths would be linearly related to precipitation length.

In industrial precipitators, however, laminar flow is practically never achieved. Consequently, the turbulent gas flow causes particles to follow a random path through the precipitator. The magnitude of the force resulting from the tubulent gas flow is large compared to the electrical force. However, at the boundary layer the gas flow is laminar and particles entering the boundary layer will be collected. The collection efficiency is therefore related to the probability of a particle entering the boundary layer. Studies by Anderson, Deutsch, and White of particle collection in a turbulent gas stream, have shown theoretically that collection efficiencies are exponentially related to the collection surface, the gas volume handled, and the migration velocity of a particle. The equation, known generally as the Deutsch-Anderson equation, is of the form $\eta = 1 - \exp\left(-A\, w/V\right)$, where $\eta$ is the collection efficiency, A is the collection electrode area, V is the gas volume flow rate and w is the migration velocity.

The derivations of the efficiency equation are based on the assumption that there is a reasonably constant distribution of the particles in any cross section of the precipitator due to turbulent mixing of the gas. In addition to this assumption, there are several basic conditions that apply to the derivation of the equation. The equation also includes no term to account for reentrainment of collected dusts, uneven distribution of the gas flow, or other factors inherent in practical precipitator operation.

A principal practical use of the Deutsch-Anderson equation has been in relating measured collection efficiency to the collecting surface area and gas volume. In such cases, the term was calculated from the Deutsch-Anderson equation as a parameter, rather than the migration velocity given by theoretical considerations. In this case, it is called effective migration velocity or precipitation rate parameter. The term is useful in describing the effectiveness with which a given dust can be collected, and is widely used in design and analysis of precipitators.

From a theoretical as well as practical standpoint, the distribution of particles within the precipitator is important. There is some evidence to indicate that particle distribution within the precipitator may not be uniform and that diffusional forces may also play a role in collection efficiency.

## Dust Removal

Once collected, the dust or liquid aerosol must be removed from the precipitator. [This can be accomplished by flowing a liquid down the collection electrode to wash the collected dust, or by rapping the electrodes to impart an acceleration to dislodge the dust, which falls into a hopper for subsequent removal.] Liquid aerosols normally coalesce and drain from the plates so that removal is not a problem.

In dry removal systems, rapping of the collection electrode to remove the dust is normally done on a periodic basis. Successful rapping depends upon accumulation of sufficient thickness of material on the plate so that it falls in large agglomerates into the hopper. There is always some reentrainment of the dust so that effective rapping must minimize the amount of material reentrained in the gas stream.

The accelerations required to remove the collected dust vary with the properties of the dust and gas stream. Forces of cohesion and adhesion consist of molecular (van der Waals), electrical, and mechanical forces. Some dusts adhere tenaciously to the collection surface and require substantial accelerations to dislodge them. Variations in operating temperature, gas composition, or both, can alter the forces required for successful rapping. Electrical forces, which are related to current density and dust resistivity, may also be significant in holding the collected material to the plate, and therefore influence the forces required for rapping. Since current densities are higher at the discharge electrode than at the collecting electrode, greater forces are often required to maintain them relatively free of dust deposits than are required at the collection plates.

The material that is rapped from the collection electrode is temporarily stored in ash hoppers until subsequent removal from the system. Careful hopper design and gas flow control are required to minimize the reentrainment of this previously collected dust".

### Types of Electrostatic Precipitators (ESP)

Two general types of electrostatic precipitators are used to control particulate emissions from stationary sources - dry and wet. Dry ESPs are used in the electric utility industry. By far the greatest number of ESPs in the service are plate type ESPs. Collection plates are spaced 8-12 inches apart with a series of discharge electrodes spaced along the centerline of adjacent plates. Approximately 3000 ft$^2$/1000 scfm of gas flow is required to achieve a collection efficiency of 99.5% when the operation is not resistivity limited.(IIB-1) Specific collection areas may increase as resistivity increases.

Within the category of dry ESPs, hot side and cold side ESPs are the most frequently used in the electric utility business. In both systems an air preheater is used to recover heat from flue gas and heat the air entering the boiler. An air-preheater allows for the opportunity to have a hot or cold side ESP. In the "hot side" system flue gas flows through the particulate control device ahead of the air preheater. These types of devices may operate on gases whose temperature averages 1290°F. "Cold-side" systems are employed after the flue gas has passed the air preheater which operates at temperatures in the range of 570 to 750°F.

Other types of ESPs include Charged Wet Scrubbers, Wet Type Precipitators, High Intensity Ionizers, and High Gradient Magnetic Collectors.

The efficiency of an ESP is primarily determined by the electrical resistivity and particle size distribution of the particulates being captured.

There is a temperature at which resistivity is maximum. Resistivity occurs less at temperatures below approximately 480°F or above 750°F. For high resistivity ash, capture is most difficult in the maximum resistivity range. The temperature at maximum resistivity usually lies in the same range as the temperature of the gas out of the steam generator air preheater (cold side) i.e., after the flue gas has been cooled due to heat exhange with the combustion air. The temperature range for effective capture is about 480°F-610°F. The resistivity of the ash entering the air preheater (hot side) is much less at temperatures ranging from 1020°F-1650°F. Generally high resistivity ash is easier to collect on the hot side than on the cold side.

If the ESP is located on the hot gas side of the air pre-heater where the flue gas temperature ranges from 600-900°F, it can operate without any limitation on performance related to the electrical resistivity of the ash. Two considerations are important. First, the volume of gas at 700°F will be approximately 50% greater than at 300°F at the same pressure, and a correspondingly greater plate area of approximately 50% will be required. Second, the 700°F temperature requires less voltage than 300°F, and thus resulting in reduction of the electrical charge on the particles as well as the electric field adjacent to the plate. Thermal expansion becomes a problem with a hot sided ESP.

## General Advantages and Disadvantages

Electrostatic precipitators are the most widely used devices for removing fly ash from the flue gas from electric power boilers. The general advantages of electrostatic precipitators for this application, in comparison with other control devices, are:

1. The system is dry, so corrosion or scaling is not usually a problem.

2. The pressure drop through the precipitator is low and the power requirement is low.

3. Gases are emitted from the stack at relatively high temperatures and not saturated with moisture, so plume buoyancy is maintained without reheat.

4. No water pollution is involved.

5. Equipment is relatively compact and maintenance and down time are relatively low.

The disadvantages are:

1. Performance (collection efficiency) depends on the chemical composition of the coal being burned, notably its sulfur content.

2. Gas flow uniformity and reentrainment of the deposited fly ash require attention to insure high collection efficiency.

3. Capital equipment costs are relatively high.

## Specifications to Meet Standards

The EPA has listed specifications for ESPs that will meet proposed NSPS standards. The following is a discussion of the matter:

> "EPA collected emission data from 21 ESP-equipped, coal-fired steam generating units. The nominal sulfur content of the coals being fired ranged from 0.4 percent to 1.9 percent. None of the 21 units tested were designed to achieve an emission level equal

to or below the proposed standard of 13 ng/J (0.03 lb/million Btu) heat input; however, emissions from 9 of the 21 units were below the proposed standard. All of the units tested which were firing coal with a sulfur content greater than 1 percent and had a hot side ESP with a sepcific collection area greater than 89 square meters per actual cubic meter per second (452 $ft^2$/ 1,000 ACFM), or a cold side ESP with a specific collection area greater than 85 square meters per actual cubic meter per second (435 $ft^2$/1,000 ACFM), had emission levels below the proposed standards. EPA evaluated emission levels from units burning relatively low-sulfur coal because it is more difficult for an ESP to collect particulate matter emissions generated by the combustion of low-sulfur coal than high-sulfur coal. ESP's require a larger specific collection area when applied to units burning low-sulfur coal, because the resistivity of the fly ash is higher with low-sulfur coal. To meet the proposed standard, EPA believes that an ESP used on low-sulfur coal will have to have a specific collection area from around 130 (hot side) to 200 (cold side) square meters per actual cubic meter per second (650 to 1,000 $ft^2$ per 1,000 ACFM) while an ESP used on high-sulfur coal (3.5 percent sulfur) would only require around 72 square meters per actual cubic meter per second (360 $ft^2$ per 1,000 ACFM).

ESP's have been traditionally used to control particulate emissions from power plants. High-sulfur coal produces fly ash with a low electrical resistivity which can be readily collected with an ESP. However, low-sulfur coal produces fly ash with high electrical resistivity, which is more difficult to collect. The problem of high electrical resistivity fly ash can be reduced by using a hot side ESP (ESP located before combustion air preheater) when firing low-sulfur coal. Higher fly ash collection temperatures improve ESP performance by reducing fly ash resistivity for most types of low-sulfur coal (for example, increasing the fly ash collection temperature from 177°C (350°F) to 204°C (400°F) can reduce electrical resistivity of fly ash from low-sulfur coal by approximately 50 percent)."(IIB-2)

## Fabric Filters (Baghouses)

Fabric filters are the least used, yet most promising, of the control technologies to limit emissions of particulates from fossil fuel power plants. The McIlvaine Fabric Filter Manual (IIB-3) contains a description of the fabric filtration process. The following detailed description is excerpted from that Manual.

### General Description*

"A fabric filter consists of a porous flexible layer of textile material through which a dusty gas is passed to separate particles from the gas stream. As particles accumulate, resistance to gas flow increases. Deposits are removed periodically by vigorous cleaning of the cloth to maintain the pressure drop across the filter within practical operating limits. Provision of methods for cleaning the fabric in place is a distinguishing characteristic of this class of gas filter.

Fabric filters are commonly used for control of dust concentrations in the range of $10^2$ ug/$m^3$ (urban atmospheric dust) to $10^3$ g/$m^{3a}$** (pneumatic conveying). They provide effective removal of particles whose sizes range from [submicron] fumes to greater than 200 [micron] (um) powders. Fabrics are available to permit operation at gas temperatures up to about 550°F and to provide chemical resistance against specific chemical constituents of the gas or particulate. Fabric filters are also used to provide a substrate for support of granular reactants or adsorbents to recover gas components.

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* Reprinted from the McIlvaine Fabric Filter Manual by permission of the McIlvaine Co., 1975.

** One gram per cubic meter = 0.435 grains per cubic foot.

The quantity of ventilation air or process gas and the dust concentration, in conjunction with specific flow resistance properties of the particulate deposit on the fabric, determine the amount of cloth area required for any selected value of operating pressure differential. An operating pressure drop is generally selected in the range of 3 to 4 inches of water, for economic reasons, but some designs operate substantially in excess of 10 inches of water. Superficial filtration velocities (total air volume filtered/total cloth area), commonly called the air-to-cloth ration, are generally in the range of 1 to 15 cfm/ft$^2$, i.e., 1 to 15 ft/min.* However, values in excess of 50 ft/min can be achieved at moderate flow resistance with certain cleaning devices on coarse dusts. High velocity filtration (100 to 2000 ft/min) may also be employed on liquid particulates.

Collectors are manufactured in sizes from a few square feet of fabric up to several hundred thousand square feet. Total gas flows handled by individual units range from less than 100 cfm to greater than a million cfm. Unit collectors up to a few hundred square feet are fabricated and assembled by semi-automatic production line techniques, produced in relatively large quantities and shipped assembled. Intermediate-sized modular units may be manufactured and shipped erected in two halves (top and bottom). Larger units are carefully designed to meet the requirements of specific applications and are frequently fabricated for assembly at the installation site. Structural units on the largest applications are erected on the site.

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* Average for shaker type, reverse air and pulse-met are approximately 2.5/1, 2/1 and 6/1, respectively.

Costs vary in proportion to size and with respect to kind and arrangement of fabric and cleaning apparatus. Initial collector costs are typically in the range of 0.50 [0.60, 1978] to 2.00 [2.40, 1978] dollars per cfm.* Actual installed costs, including necessary auxiliary equipment, may be 1.1 to 10 times the base cost of the filter, a figure of 3.5 times being suggested as a reasonable average estimating approximation. Fabric filters are seen to yield lower penetrations (higher efficiency) at costs lower than those predicted from the guideline shown. This favors fabric filters in those situations where their use is not precluded by other factors, and where very high collection efficiency is required for fine particles. Generally, high efficiency at reasonable cost is an inherent characteristic of the separation process utilized in fabric filters. If they are properly designed, installed, operated and most importantly, properly maintained, fabric filters will collect more than 99.9% of the incoming dust on most applications.

If the conveying gas is respirable, the discharge from the fabric filter can be returned to the interior of the plant, in many industrial applications, as it will be respirably acceptable. This effects a saving on the heating or cooling of make-up air. The collector discharge dust concentration will frequently be found to be less than 100 ug/$m^3$ which is as low or lower than ambient atmospheric dust concentrations found in many major U.S. cities. In general, increased outlet concentrations are associated with higher inlet concentrations, more cleaning energy, and higher filtering velocities.

### Operating Principles

A fabric filter is made up of a woven or felted textile material in the shape of a cylindrical bag, sleeve, flat supported envelope or pocket. The textile material is contained in a metal housing which has inlet and outlet gas connections, a dust storage hopper and means for cleaning the fabric periodically. Woven fabrics consist of parallel rows of yarns in a square array. Open spaces between adjacent yarns are occupied by projecting fibers. Felted fabrics consist of close, randomly intertwined fibers compacted to provide fabric strength. In operation, dusty gas passes through the filter normal to the fabric at the start of the filtration. Dust particles are deposited on individual fibers and yarn surfaces at the start of the filtration. Additional particles are then deposited and accumulate on previously deposited particles, forming filamentous aggregate - tree-like branched structures - which project into the gas stream. As deposition and accumulation continue, openings between yarns and individual fibers become occupied by aggregates and reduced in size. Eventually, a more or less continuous deposit forms, analogous to the filter cake common in liquid filtration. Particle collection then occurs by the use of mechanisms associated with flow through and deposition on porous granular media. The fabric filtration process may be considered to consist of at least three distinct phases: (1) initial or early deposition, when depositing particles land on individual fibers, fibrils or filaments of the yarn; (2) intermediate deposition when particles accumulate on previously deposited particles, long filamentous particle aggregates form and bridging of interweave and interstitial spaces occurs leading to the formation of a more or less continuous deposit; and (3) the continued deposition of particles on a matrix similar to a granular layer, leading to the formation and consolidation of a filter cake.

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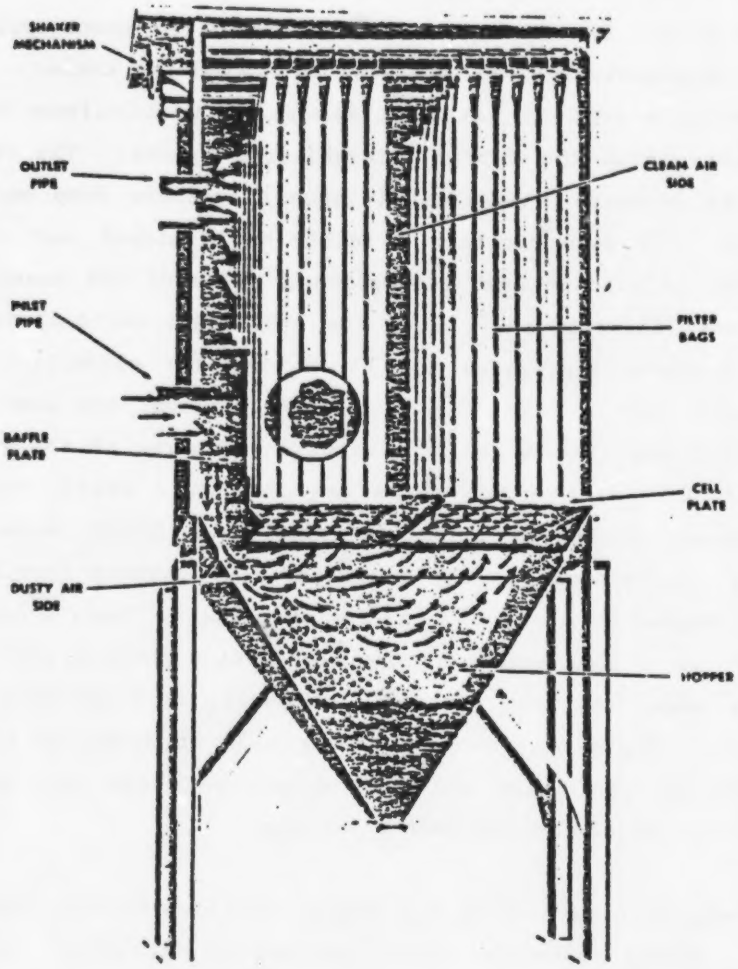
* Mid-1975 U.S. dollars.

Accumulation of dust causes an increase in gas flow resistance as a consequence of particle drag and interparticle pore (capillary) resistance. The properties of the particle bed (porosity, permeability) also change during the formation of the deposit.

Aggregates deform, bend, collapse, or reorient under the action of the gas flow and the increasing pressure on the bed as its depth increases.

The filter bag (sleeve, tube, envelope or pocket) is supported by external and sometimes internal structures to permit the dusty gas to flow through the housing from an inlet section to a clean gas outlet section. This is shown in Figure B.1 in one of several typical arrangements. In the particular arrangement, the bag is fastened at the bottom to a tube sheet or cell plate and held up vertically by a top hook on an overhead rack. The bag may be pulled to the desired tightness by means of a tension adjustment. Gas flows into the inside of the bag from the bottom and passes up to the interior and through the bag to the outlet ducting. The gas may then go to the suction inlet of a blower and hence out of the system, either returning to the ventilated space or to the outdoor atmosphere. Alternatively, the blower can be located on the inlet side of the fabric filter so that it draws air or gas from the ventilated system or process and discharges it to the bag collector under pressure. In this latter case, as before, the gas passes through the fabric leaving the dust on the inner surface and the gas is then discharged.

There are several methods of removing the dust from the inside of the filter bags. In the design shown, the dust may be removed by stopping the flow and allowing the dust to fall off by its own weight; or the dust is removed (by vigorously oscillating the suspension rack back and forth through an amplitude of a few inches). This shaking motion, imparted to the bags in the absence of flow, causes sufficient forces to be transmitted to the deposit to separate some of it from the fabric substrate. The dust then drops down the interior of the bag, through the opening of the bag at the tube sheet, and into the hopper. Collected dust is removed from the hopper periodically or continuously for disposal or return to the production process.


SHAKER MECHANISM
OUTLET PIPE
CLEAN AIR SIDE
INLET PIPE
FILTER BAGS
BAFFLE PLATE
CELL PLATE
DUSTY AIR SIDE
HOPPER

Typical Fabric Filter Arrangement

(Wheelabrator Dust-Tube,
Wheelabrator-Frye Corp.)

Source: Reference II.B-3

FIGURE B.1

Adhesion forces holding individual particles together or to the underlying fibers or yarns exist over a range of values. The application of a cleaning force by shaking initially removes a large amount of the deposit on the first few shake cycles, but then progressively less and less on succeeding cycles. A substantial amount of residual deposited particulate material remains within the fabric interstitital spaces. The remaining deposit produces a residual (cleaned) pressure drop across the fabric. It also provides a fairly high initial particle collection efficiency upon resumption of flow of the dusty gas on the next filtration cycle as the individual residual particles and particle aggregates act as objects for collection of the incoming dust. Upon resumption of filtration, the dust deposit rapidly acquires a uniform porosity because of the residual material Within the total bag structure these deposition processes proceed at different rates at different areas of the fabric in response to the amount of flow passing locally, this flow depends on the amount of residual dust. Thus, a local area which has a more porous or open residual structure will tend to allow more flow and, initially at least, material will deposit faster. These initial differences tend to (even out) so that filtration velocities and dust deposition rates tend to become uniform over the entire fabric surface.

Gas passing upward through a single bag flows outward through the bag causing velocity inside the bag to decrease. Since the particle gas motion is vertical, there are flow and particle stratification effects which enter into the analysis of the macroscopic processes of deposition, accumulation, and gas flow through the media. The upward flow within the bag, the turn of the gas in leaving the hopper and in entering an individual bag, tends to separate larger particles out of the flow by gravity or inertia. Larger particles carried into the tube are deposited in the lower end of the tube as the gas velocity progressively decreases as it rises. This stratification of particle sizes has important consequences on deposit characteristics and on fabric performance and life over the entire bag length, but particularly at the bottom near the entry, usually a point of maximum wear.

The operation cycle of the fabric filter contains two phases. The first is a filtration phase during which material is depositing and accumulating on the fabric while pressure drop across the deposit is increasing and total flow is decreasing. The second is a cleaning phase with no filtration flow during dust removal. By compartmenting sections of bags and isolating these one at a time from the gas flow for cleaning, the total flow from the process ventilated can be maintained at a reasonably constant pace. This cleaning procedure can be automatic and the operation continuous. The residual dust deposited and retained within the fabric interstices gradually reaches an equilibrium value after numerous filtration and cleaning cyles, after which the residual pressure drop remains more or less constant throughout the useful life of the fabric ( $10^4$ - $10^7$ cleaning cycles).

## Particulate Collection Efficiency

Particles entering a new fabric initially contact individual fibers, fibrils, and yarn filaments and are separated from the gas by several filtration mechanisms. Deposited particles serve as additonal obstacles for further capture of other particles. After cleaning, the residual dust provides a substantial number of obstacles for further particle collection. The collection efficiency of a fabric filter is defined as:

$$\text{Efficiency} = 1 - \frac{\text{Outlet Dust Concentration}}{\text{Inlet Dust Concentration}} = 1 - \text{Penetration}$$

It may be determined for an operating filter from simultaneous measurements of inlet and outlet dust concentrations by appropriate stack sampling techniques.

The basic collection efficiency of new filter fabric is generally in the range of 50 to 75% for submicron atmospheric dust (0.5 um count median diameter, and an inlet concentration of 75 $ug/m^3$) at 3 to 8 ft/min. As dust accumulates, efficiency rises. By the time the deposit amounts to 2 to 3 grams of dust per square meter (~3 to 5 grains per square foot) the collection efficiency usually exceeds 90%. This happens in about one minute at an inlet dust concentration of 2.3 $g/m^3$ (1 $gr/ft^3$), a common industrial dust loading. Overall efficiency then continues to increase with dust accumulation and will generally exceed 99% when the deposit reaches 150 $g/m^2$ (0.03 $lb/ft^2$), i.e., after an hour or less at common industrial dust concentrations.. After a period of cyclic filtration and cleaning ranging from a few hours to a few days, the residual deposit will stabilize and thereafter efficiency will remain greater than 99%. During usual operating conditions, fabric filter overall weight collection efficiency will exceed 99.9%. The collection efficiency for the submicron fraction of the inlet dust is usually greater than 90%.

The high overall efficiency is related to the nature of the accumulated deposit. Overcleaning in order to reduce flow resistance will frequently cause a reduction in overall efficiency and a slight visible puff of dust may be observed upon resumption of filtration. The dust collection efficiency for the submicron fraction may then be less than 80% until cake formation. Overcleaning can also shorten the life of the fabric and increase cost of maintaining the filter system. Fabric life averages about one to two years, although it can vary from a few weeks up to 20 years depending upon application. Fabric life and filter performance depend on the design of the filter, the application conditions and operation and maintenance of the filter system."

## Advantages and Disadvantages

Principal advantages of fabric filter systems in many installations are:

- Particle collection efficiency is very high and can be maintained at high levels.

- Efficiency and pressure drop are relatively unaffected by large changes in inlet dust loadings for continuously cleaned filters.

- Filter outlet air may be recirculated within the plant in many cases.

- The collected material is recovered dry for subsequent processing or disposal.

- There are no problems of liquid waste disposal, water pollution, or liquid freezing.

- Corrosion and rusting of components is not usually a problem.

- There is no hazard of high voltage, simplifying maintenance and repair and permitting collection of flammable dusts.

- Use of selected fibrous or granular filter aids permit the high efficiency collection of submicron smokes and gaseous contaminants.

- Filter collectors are available in a large number of configurations resulting in a range of dimensions and inlet and outlet flange locations to suit installation requirements.

Limitations in the use of fabric filters include:

- Fabric life may be shortened in the presence of acid or alkaline particle or gas constituents, and at elevated temperatures.

- Temperatures much in excess of 500°F require special refractory mineral or metallic fabrics that are still in the development stage.

- Hygroscopic materials, condensation of moisture, or tarry, adhesive components may cause crusty caking or plugging of the fabric or require special additives.

- Certain dusts may require fabric treatments to reduce seeping of the dust or in other cases to assist in the removal of the collected dust.

- Concentrations of some dusts in the collector ($\sim 50\ g/m^3$) may represent a fire or explosion hazard if spark or flame is admitted by accident. Fabrics can burn if readily oxidizable dust is being collected.

- Replacement of fabric may require respiratory protection for maintenance personnel.

## Wet Scrubbers

Scrubbers are not commonly used for control of particulates from coal-fired steam generators unless the source is equipped for flue gas desulfurization (FGD). The Gas Atomized Spray type scrubber (popularly known as the Venturi scrubber) is the most common type of scrubber applied for scrubbing particulates from the flue gas of coal-fired steam generators. For the purpose of this study, it will be the only type of scrubber considered even though there are 12 other categories of scrubbers that are applied mostly to industrial processes.

### Description

The following description of Gas Atomized Spray scrubbers is taken from the McIllvaine Scrubber Manual.(IIB-4)

> "General* This category involves collectors relying on acceleration of the gas stream to provide impaction forces and intimate contact with the liquid stream, and atomization of the liquid stream to provide targets for dust particles and contact area for absorption.
>
> Most distinctive regarding this group of scrubbers is the wide range of pressure drop that is obtained. Scrubbers in this group operate between 3" and 50" w.g. pressure loss across the scrubbing section.
>
> The units have been only available commercially since approximately 1947, subsequent to work by Johnstone at the University of Illinois. This is despite knowledge dating back to 1900 on the potentially high efficiency of venturi scrubbing.

*Reprinted from the McIlvaine Scrubber Manual by permission of the McIlvaine Co., 1974.

The acceleration of the gas stream is achieved by reduction of the gas flow area. It was first thought that maximum efficiency per unit of energy consumed could be achieved only by maximizing particle velocity. Therefore, the true venturi shape was considered ideal since acceleration could be achieved with the minimum energy input.

Consequently during the 1950's, high energy scrubbing involved classical venturi throats. Chemical Construction was the primary supplier of Venturi scrubbing equipment during this period.

During the 1960's, Research Cottrell and others found that turbulence was a positive factor in dust removal and, therefore, that an orifice which created much more turbulence than a true venturi was equally efficient for a given unit of energy consumed.

As a result of these findings, a number of manufacturers began building annular orifice collectors. The individual scrubbers within this group differ from each other in the following design aspects.

(1) Method of acceleration. In addition to the two designs described above, the true Venturi and the annular orifice, there are other designs for gas acceleration. A baffle across part of the inlet duct is the acceleration method used by the Ducon Oriclone and Peabody Venturi Slot. The Environeering Venturi Rod scrubber used rods to provide the restriction.

(2) The method of adjusting pressure drop. Various automatic devices for varying the throat opening are available. In the true Venturi, a damper can be

provided to reduce the throat size. A flat damper greatly impairs the flow characteristics so various damper designs have been used which simulate the true Venturi shape at various pressure drops.

In the annular orifice, the center disc can be moved up and down to vary the throat opening. In the Research Cottrell unit, the support shaft for the disc is below the disc; in others, it is located above.

(3) The method of water introduction. Liquid can be sprayed into the restricted area as in the Environeering Ventri Rod, or several of the venturi scrubber designs, or it can be cascaded over a weir on the sides as in the Chemico design.

In the case of the flooded disc scrubber, the water comes up the central shaft and flows out across the disc.

Where the liquor [cleansing liquid] is cascaded into the orifice in either the Venturi or annular orifice, the opening width becomes a critical factor. One manufacturer of the true Venturi limits throat width to 15" to assure adequate liquid mixing. A manufacturer of an annular ring scrubber has limited the opening to 2" for the same reason.

Another method of liquid introduction includes the use of splash plates. In the American Air Filter Kinpactor, the liquid discharges from small pipes at high velocity onto a splash plate from which it is deflected into the gas stream. In some annular ring collectors, liquor is added from the outer shell as well as from the inner disc.

(4) Method of Moisture Elimination. Most gas atomizer designs utilize a centrifugal moisture eliminator. The gas enters tangentially after leaving the throat and making a 90° turn to drop out most of the liquor. It then travels through the centrifugal tower at 400-500 fpm.

A variation of the centrifugal eliminator includes spinning vanes to give more positive centrifugal action.

Another variation is a series of multiple centrifugals such as the Type "R" rotoclone which is used as a moisture separator by American Air Filter following the Kinpactor venturi.

Chevron eliminators are used by some manufacturers. Gas velocity is 500-800 feet per minute.

## Particulate Collection Efficiency

By increasing the energy consumption to above 100" pressure drop, very efficient collection can be obtained on sub-micron fumes from furnaces and other combustion processes. However, certain dusts resist collection at even 150" w.g. Examples include ammonium nitrate fumes from prill towers, a blue haze from refractory brick kiln drying, and fume from oil fired boilers.

Many emission sources can be brought into compliance with scrubbers utilizing pressure losses from 5 to 40" w.g. The vast majority of scrubbers in this group operate in this pressure range. Particulate efficiency is higher for this group than other types of scrubbers. It is also higher than centrifugal collectors and in a number of cases e.g., utility boilers, more efficient than electrostatic precipitators. However, fabric filters normally provide higher efficiency.

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# APPENDIX IIC

## Geysers Monitoring Program

## APPENDIX II.C

### Introduction

This appendix reproduces in part the summary of the Geysers monitoring program as reported in reference IIC-1.

It should be noted that the references are as they appear in the original text.

"A. Measurements of Radon Emissions

1. $^{222}$Rn Emissions from the Geysers Power Plant. Measurements of the $^{222}$Rn concentration in the steam delivered to the turbine of each unit has been made. The results of these measurements are shown in Table 7-2 of Chapter II. The approximate maxiumum release rate for the 11 units is 1.43 Ci/day. The Geysers units operate continuously at full power except for maintenance, forced curtailment, or shutdown. If an outage is anticipated to last only a few days, the steam may be routed to other units or in some cases vented to the atmosphere through mufflers. During long-term outages, the wells are usually shut in except for a small bleed. The overall 1972 and 1974 availability factor for The Geysers Power Plant was 0.89. A reasonable estimate of the average $^{222}$Rn release per unit of produced power, based on plant operating records, is approximately 3.2 mCi/(MWe-day).

At the time most of these measurements were made, the $^{222}$Rn was released with the noncondensable gases through a single stack at each unit. $^{222}$Rn concentrations in the stacks of the units varied from 2460 to 6840 pCi/l. By late 1976, the gas-ejector effluents at all units had been ducted to their respective cooling towers. The large volume of air drawn through the cooling tower thereby greatly dilutes the gas-ejector effluents, and thus lowers the $^{222}$Rn concentration in the cooling tower exhaust to less than 2.0 pCi/l. ..."

"An ambitious program is underway to reduce the $H_2S$ releases from The Geysers Power Plant. One technique being presently applied on existing units is a backfit system which introduces iron sulfate catalyst to the steam condensate. Most of the $H_2S$ contained in the condensate and the noncondensable gases is oxidized to elemental sulfur which accumulates in the cooling tower basin before removal to a landfill disposal site. The treated gases are then released through the cooling towers as previously mentioned. A second technique, called the Stretford Process, is being designed into Units 13 and higher. In this process, a surface condenser is used to partition most of th $H_2S$ with the noncondensable gases. These gases are then washed in a catalytic solution to produce a sulfur product. The $^{222}Rn$ and the other noncondensable gases are not affected by this process and will be diluted by the cooling tower exhaust air as in the existing units. A discussion of radionuclides in the sulfur product and cooling tower sludge is presented in a later section.

2. Rates of $^{222}Rn$ Exhalation from Soil. Rates of $^{222}Rn$ exhalation from soil were measured at 11 sites in The Geysers area. The data varied from $2.6 \times 10^{-6}$ to $150 \times 10^{-6}$ pCi/(cm$^2$-sec) or 0.05 to 2.6 atoms (cm$^2$-sec), which is comparable to the world-wide average (Wilkening, et al, 1972). As expected, there was a strong correlation between the exhalation rate of $^{222}Rn$ from soil and the concentration of its parent $^{226}Ra$ in soil.

3. Rate of $^{222}Rn$ Emission from a Fumarole. The concentration of $^{222}Rn$ in the noncondensable gas effluent from one natural fumarole, and the rate of emission of noncondensable gases, were measured to determine the rate of $^{222}Rn$ emission. The concentration of $^{222}Rn$ in noncondensable gas was high, 2630 pCi/l, but the emission rate was only 0.66 pCi/sec. This is equivalent to the rate of exhalation from 1.6 m$^2$ of soil surface with a world-wide average rate of exhalation of $42 \times 10^{-6}$ pCi/(cm$^2$-sec).

## B. Measurement of $^{222}$Rn and Short-Lived Radon Daughter Concentrations

1. Short-term (5 min) measurements. Between July 16, 1974 and January 7, 1975, 266 measurements of the concentration in air of the three short-lived daughter radionuclides of $^{222}$Rn: RaA, RaB, and RaC were made. The results were highly variable and ranged from 0.00015 WL to 0.105 WL. Only a few well-defined types of locations were associated with the highest concentration, and measurements at these sites also indicated a marked disequilibrium of RaA:RaB:RaC. These locations, in which 27 measurements were made, were inside the steam exhaust pipes and condensers at Units 1-4 shortly after the units were shut down, immediately over the manhole of the hotwell at Units 1 and 2, and the effluent from the Unit 2 gas-ejector. The highest concentration measured during this study was 0.105 WL inside the steam exhaust pipe at Unit 4. The reference standard of 0.01 WL for uncontrolled areas is for 24 hr/day with averaging allowed over a year (CFR 1977). Therefore, a useful calculation is the fraction X of time that a worker could spend in a concentration of 0.105 WL without exceeding the reference standard.

$$0.105X = 0.01$$
$$X = 0.095$$

The fractional amount of time that a worker actually spends at work is approximatley 40/168 = 0.24, so a worker could spend 0.095/0.24 or 40 percent of his working hours in a concentration of 0.105 WL without exceeding the reference standard for uncontrolled areas.

All of the locations that significantly exceeded the reference standard were inside the steam exhaust pipes and condensers at Units 1-4. The concentration of short-lived daughters drops very rapidly (on the order of a few minutes) once ventilation is established by opening the access hatches to both the exhaust pipe and the condenser. It is

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now recommended operating procedure at the Geysers to open both hatches before entering these areas (Serpa 1977).

The remaining 239 measurements, which were made at sites throughout The Geysers and surrounding areas, appear to be fairly homogeneous and display the expected variation due to meterological conditions which have been reported by others (Cohen 1972; Jacobi and Andre 1963, Wilkening, et al. 1972). A lognormal distribution (Larsen 1971; Schubert, et al. 1967) was fit to these 239 measurements with the following results:

Measured highest concentration = 0.0080 WL
Measured lowest concentration = 0.00015 WL
Calculated geometric mean = 0.0011 WL
Calculated geometric standard deviation = 2.1
Calculated arithmetic mean = 0.0015 WL

The reference federal concentration standard is 0.01 WL above background averaged over a year (CFR 1977).

2. Long-term (1 week) measurements. From February to December 1975, nearly 600 weekly measurements of the concentration in ambient air of the short-lived daughter products of $^{222}$Rn were made at 37 locations including several downwind communities. The results ranged in value from 0.00004 to 0.003 WL with an average of 0.0005 WL, and support the conclusion of the short-term measurements that there is no discernible influence of The Geysers Power Plant operation on the ambient air concentration of the short-lived daughters of $^{222}$Rn.

3. Uncombined Fraction of Short-Lived Radon Daughters. Eighteen attempts were made to measure the concentration of uncombined atoms of RaA. Concentrations of uncombined atoms were typically very small and had a high error of measurement. Only three measurements can be considered valid at the 99 percent confidence level. For these three

measurements, the uncombined fractions of Ra activity were calculated to be 0.29, 0.15, and 0.04.

4. 222Rn Concentration in Air. The concentration of $^{222}$Rn in ambient air was also measured. Preliminary measurements were made on December 18 and 19, 1974, at nine locations. They varied from 0.03 to 0.37 pCi/l. The federal reference standard is 1 pCi/l for uncontrolled areas (CFR 1977).

Longer term measurements were made with continuously recording systems. System 1 was installed in the Units 1-2 turbine building from October 1, 1975 through December 4, 1975, and then at SRI Station 7 on Bottle Rock Road (Sawmill Flat) from December 5, 1975 through December 18, 1975. System 2 was operated in the Units 1-2 turbine building over the entire period from October 1, 1975 through December 17, 1975. The highest recorded $^{222}$Rn concentration during these time periods were 0.5 pCi/l at Units 1-2 and 1.4 pCi/l at SRI Station 7. The concentration of $^{222}$Rn at SRI Station 7 was substantially less than 1.4 pCi/l most of the time, and well below the federal reference concentration standard of 1 pCi/l averaged over a year (CFR 1977).

## C. Measurement of Long-Lived Radon Daughter ($210_{Pb}$) and Other Radionuclides in Air

1. Mass, $210_{Pb}$, and $^{230}$Th Concentrations in Air and Their Distribution with Particle Size. Two Anderson-2000 cascade impactors were operated at The Geysers for 5 two-week sampling periods beginning on February 19, 1975. One impactor was located inside the Units 1-2 turbine building and the other was located outside of Units 3-4 west of the turbine building. Air particulate mass results varied from 36 to 62 ug/m$^3$ inside Units 1-2 and from 12 to 32 ug/m$^3$ outside Units 3-4. Mass median aerodynaimic diameters (MMAD) were about 1 um inside Units 1-2 and about 2 to 3 um outside Units 3-4.

Concentrations of $^{210}$Pb were roughly 3 and 6 fCi/m$^3$ at Units 1 and 2, and 3 and 4, respectively. These values are essentially the same as those measured at Livermore, California (Gudiksen, et al. 1972; Lindeken 1966), and far below the reference concentration standard of 4000 fCi/m$^3$.(CAC 1976, CFR 1977) Concentrations of $^{230}$Th in air are suspect because of analytical difficulties, but are reported as 0.3 and 0.2 fCi/m$^3$, respectively. These values are higher than those reported for a site in Illinois (Seldet, et al. 1974), but are far below the reference concentration standard of 80 fCi/m$^3$ (CAC 1976; CFR 1977).

$^{210}$Pb was primarily associated with submicron particles, while the calculated activity median aerodynamic diameter (AMAD) were 5 and 3 um for $^{230}$Th.

2. Concentration of $^{210}$Pb and Gamma-emitting Radionuclides in Air. The 100 ft$^3$/min Roots blower was operated for several 24-hour and longer time periods in September, October, and November 1975. Eight filters were analyzed for $^{210}$Pb and gamma-emitting radionuclides. $^{210}$Pb concentrations varied from 4.8 to 23 fCi/m$^3$. These values are essentially the same as those reported in the literature (Silver, et al. 1976), and far below the reference concentration standard of 4000 fCi/m$^3$ (CAC 1976; CFR 1977). Concentrations of $^7$Be, $^{95}$Nb, $^{106}$Ru, $^{125}$Sb, $^{137}$Cs, and $^{144}$Ce were also detected for some or all of these sampling runs. Values for all radionuclides were similar to those reported at other locations (Silver, et al. 1976). This is, of course, expected because $^7$Be is cosmogenic and the other gamma-emitting radionculides reported are derived from world-wide fallout of nuclear weapons tests.

## D. Concentration of $^{210}$Pb in Vegetation

Thirteen vegetation samples were collected at The Geysers and Vicinity on December 29, 1975, and analyzed for $^{210}$Pb. The results vary from 0.09 to 0.95 pCi/g dry weight. These values are essentially the same as those reported for other locations (Blanchard 1967; Holtzman 1966, Kauramen and Mittinen 1969; LFE 1975).

### E. Concentration of $^{226}$Ra and $^{210}$Pb in Water and Steam Condensate

Thirty-six water and steam condensate samples were collected at The Geysers and vicinity in the summer of 1974. The results were all below the detectable limit for the analysis (0.0001 to 0.0002 pCi/cc for $^{226}$Ra, and 0.001 to 0.006 pCi/cc for $^{210}$Pb). These values are comparable to those values reported elsewhere (Eisenbud 1973; Langford 1971; and LFE 1975).

### F. Concentration of Gamma-emitting Radionuclides in Soil and Terrestrial Gamma Exposure Rates

Thirty measurements of gamma-emitting radionuclides in soil were performed at The Geysers and vicinity using the technique of field spectrometry (Auspaugh, et al. 1972; Beck, et al. 1972; Camp et al., 1974). The results are summarized in Table C-1 and compared to the results of measurements at about 800 other sites in the western United States. The concentrations of gamma-emitting radionuclides in soil at The Geysers are typical of other locations in the United States (Anspaugh, et al. 1972), although it is of interest that substantial variations do occur within fairly short distances.

Of particular interest is the concentration of $^{226}$Ra which is the parent radionuclide of $^{222}$Rn. Sixteen of the values are between 0.5 and 0.8 pCi/g. Of the seven values above 0.8 pCi/g, only one was measured within The Geysers Power Plant area (near Units 7 and 8), the other six were all measured in the Bottle Rock Road-Cobb-Anderson Springs area. These higher levels of $^{226}$Ra in soil are probably the cause of the higher measured values of $^{222}$Rn in ambient air measured at SRI Station 7 on Bottle Rock Road (Sawmill Flat). The external

## TABLE C-1

### The Range of Concentration of Naturally Occurring Radionuclides in Soil and of the External Exposure Rate Due to These Terrestrial Sources

| Radionuclide | Concentration, pCi/g Minimum | Concentration, pCi/g Maximum | External Exposure Rate, uR/hr Minimum | External Exposure Rate, uR/hr Maximum |
|---|---|---|---|---|
| A. **800 LLL measurements in the western United States** | | | | |
| $^{40}K$ | 0.21 | 39 | 0.038 | 7.0 |
| $^{232}Th$ | 0.028 | 4.3 | 0.079 | 12 |
| $^{226}Ra$ | 0.074 | 3.0 | 0.13 | 5.4 |
| B. **22 LLL measurements at The Geysers and vicinity** | | | | |
| $^{40}K$ | 0.21 | 23 | 0.038 | 4.1 |
| $^{232}Th$ | 0.028 | 2.1 | 0.079 | 6.0 |
| $^{226}Ra$ | 0.074 | 1.9 | 0.13 | 3.5 |

gamma exposure rates were calculated from the soil radionuclide data. The total calculated terrestrial exposure rates vary from 0.42 to 12.9 uR/hr, which is comparable in the United States range of less than 0.1 uR/hr to approximately 24.0 uR/hr (NCRP 1975).

## G. Total External Gamma Exposure

In addition, 38 direct measurements of external exposure rate were made using a pressurized ion chamber (DeCampo, et al. 1972). Measurements were made at the locations where field spectrometric measurements were made of radionuclides in soil, and also at several locations where it had been initially postulated that there might be an accumulation of short-lived, gamma-emitting daughter radionuclides of $^{222}$Rn.

The results ranged from 5.4 to 17.3 uR/hr. These measurements included a contribution due to cosmic rays of about 4 uR/hr. All values above 10 uR/hr were measured at locations outside of The Geysers Power Plant area, and reflect the content of naturally occurring radionuclides in soil.

## H. Concentration of $^{210}$Pb and Gamma-emitting Radionuclides in Cooling Tower Sludge and Stretford Sulfur Product

Samples of the sludge that accumulates in the cooling tower basins of units without $H_2S$ abatement have been analyzed for $^{210}$Pb and other gamma-emitting radionuclides normally present in ambient air. The results of these analyses varied from 3.0 to 15 pCi/g for $^{210}$Pb.(Serpa 1975). Concentrations of $^{137}$Cs and $^{125}$Sb from fallout were approximately 0.3 pCi/g and 1.4 pCi/g, respectively. As the concentrations of $^{210}$Pb found in the cooling tower sludge were higher than those in ambient soil, determination of the source of $^{210}$Pb present in the sludge was made. Using the airborne $^{210}$Pb data presented above, calculations of the expected $^{210}$Pb concentration in the sludge due to the scrubbing of the radioactive particulates contained in ambient air moving through the tower were made. These calculated values for $^{210}Pb$ are esentially the same as those measured in the sludge. Similar comparisons for the two fallout radionuclides verified the effectiveness of the particulate scrubbing action of the cooling towers. Therefore, it was concluded that the $^{210}Pb$ present in the sludge due to the radioactive decay of $^{222}Rn$ during transport of the steam from the field to the turbine and $^{210}Pb$ contained in the particulates carried with the steam are insignificant.(Serpa 1975)

Installation of the ion catalyst $H_2S$ abatement systems and resultant elemental sulfur production decreases the radionuclide concentration in the cooling tower to that of ambient soil. Daily sludge production in an $H_2S$ abated 110 MWe unit results in the production of approximately 7.0 tons of elemental sulfur compared to aproximately 0.5 tons of particulates, rock dust, and naturally oxidized sulfur produced in an unabated unit (Serpa 1975). $^{210}Pb$ concentrations measured in Unit 11 cooling tower sludge samples ranged from 0.3 to 1.9 pCi/g dry (Serpa 1977).

The expected $^{210}Pb$ concentration in the sulfur product produced by the Stretford Process has been calculated. As previously mentioned, this process, planned for the newer units, treats the noncondensable gases removed from the surface condenser. Any $^{210}Pb$ present in delivered steam should be washed out in the condensation process leaving radioactive decay of $^{222}Rn$ during the treatment process as the only source of $^{210}Pb$ in the sulfur product. This concentration is estimated to be on the order of $1 \times 10^{-4}$ pCi/g (sulfur)/sec of retention time in the Stretford Process. Although retention times have not been fully determined as yet, they are expected to be of such duration as to preclude $^{210}Pb$ concentrations in the product from approaching those concentrations that exist in ambient soil.

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